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# GUIDELINES FOR PREDICTING THE EFFECTS OF UNDERWATER EXPLOSIONS ON SWIMBLADDER FISH

BY DAVID JOHN O'KEEFFE

RESEARCH AND TECHNOLOGY DEPARTMENT

28 MARCH 1984

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report is a guide for predicting the effects of underwater explosions on swimbladder fish. Computer calculations have been made covering a wide range of fish sizes, explosive charge weights, and depths of burst. Contour plots of kill probability are presented along with equations depicting maximum range in terms of charge weight. A criterion is established which should aid in minimizing fish-kill, and an upper limit is set on the lateral extent of kill for a given charge weight.		

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## FOREWORD

This report deals with the prediction of the effects of underwater explosions on swimbladder fish and is part of a continuing study of the effects of underwater explosions on marine life. Swimbladder fish are especially vulnerable to explosions, and this class includes most fish of sport and commercial value. This study will result in an improved capability to predict such effects and thereby reduce or avoid injury. It will be useful in connection with a variety of Naval research operations and will also apply to underwater blasting for channel clearance or for construction.

This study is part of the Ordnance Pollution Abatement Program of the Naval Sea Systems Command (SEA 62R) under Program Element 63721N, Work Unit: Environmental Effects of Explosive Testing.

The author is indebted to Robert Thrun and John F. Goertner for their assistance in the computer calculations and to George A. Young for many valuable suggestions during the course of this work.

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## GUIDELINES FOR PREDICTING THE EFFECTS OF UNDERWATER EXPLOSIONS ON SWIMBLADDER FISH

### INTRODUCTION

In many operations which require the detonation of conventional explosives underwater (the removal of hazards to shipping, the explosive cutting of abandoned oil wellheads, seismic exploration, experimental testing for military purposes, etc.) federal law requires that: (1) all possible adverse environmental effects be examined, and (2) at least a preliminary environmental assessment be prepared. Possible adverse environmental effects include noise, the deposit of chemical products in the water and atmosphere, cratering, as well as the killing of fish and other marine life. The impact of any one of these effects on the environment will, of course, depend on the particular explosive operation. However, it is safe to say that in any underwater explosion at least a few fish will be killed, and it is important to be able to estimate just how many.

This report provides guidance for predicting the effects of underwater explosions on swimbladder fish. Computer calculations of fish-kill have been made covering a wide range of fish sizes, explosive charge weights and depths of burst.

### BACKGROUND

We are principally concerned with the lethal zone around an underwater explosion for fish with swimbladders. This class includes most fish of commercial or sports value. In addition, swimbladder fish have been found to be more vulnerable to explosions than non-swimbladder fish, such as flat fish and shell fish.<sup>1</sup>

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<sup>1</sup>Wiley, M. L., Gaspin, J. B., and Goertner, J. F. "Effects of Underwater Explosions on Fish with a Dynamical Model to Predict Fish Kill," Ocean Science and Eng., Vol. 6, 1981, p. 223.

## THE CALCULATION

The basic question is how to determine the probability that a fish will be killed when subjected to a specific explosion-induced pressure wave. Until recently there has been no reliable quantitative technique available to answer that question. However, in 1978 Goertner<sup>2</sup> devised such a method and programmed it for a computer. The key to the problem turned out to be the fish swimbladder, since fish mortality due to an underwater explosion was usually traceable to swimbladder damage. Goertner represented the swimbladder as a spherical bubble of air in an infinite body of water and calculated its oscillatory response to the explosive pressure pulse. It was found that a strong resonance occurred when surface cutoff (the arrival of the rarefaction wave reflected from the water surface) coincided with maximum bladder compression. The result was maximum damage to the fish. The complete calculation is fairly complicated, since it involves: (1) the explosive pressure signature; (2) the fish swimbladder model; and (3) the interaction of (1) and (2) for numerous geometries.

## CONTOUR PLOTS

In order to simplify the presentation of the fish-kill results, the computer program was modified to produce contour plots of kill probability. They are shown in Figures 1 through 36. The relevant parameters are: (1) charge weight; (2) depth of burst; and (3) location and size of the fish. Contours depicting 90%, 50%, and 10% probabilities of fish-kill are plotted in each figure. For example, Figure 16 shows predicted regions of greater than 10%, 50%, and 90% kill (defined by the solid, dotted and dashed lines, respectively) for 1-oz swimbladder fish for a 100 pound charge at a depth of burst of 200 feet. For practical purposes the 10% contour defines the range or extent of the kill zone, although many fish will survive at positions closer to the charge. The 50% contour is more useful for estimating the actual numerical kill if the fish population density is known.

In Figures 1 through 36 the charge sizes range from 10 pounds to 10,000 pounds, while depths of burst vary from 10 feet to 200 feet. Fish weights are: 1 ounce; 1 pound; and 30 pounds.

These contour plots should bracket most situations encountered in underwater detonations in terms of fish size, charge weight, and depth of burst.

Estimates of the accuracy of the computer calculations for the 50% contour indicate that a 90% confidence limit can be placed on the 10% and 90% contours. This means that one can cite the horizontal range (at a given depth) taken from the 50% contour and be 90% confident that that number will be bracketed by the horizontal range taken from the 10% and the 90% contours (at the same depth).

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<sup>2</sup>Goertner, J. F., Dynamical Model for Explosion Injury to Fish, NSWC TR 76-155, Dec 1978.

Figures 37, 38, and 39 are plots of the maximum horizontal range of the 10% contours versus the charge weight for a given fish size. The solid lines, which are seen to represent the calculated points quite well, indicate that the maximum horizontal range is a function of the charge weight. That is,

$$H_{\max} = kW^a$$

where  $H_{\max}$  is the maximum horizontal range, in feet,  $W$  is the charge weight, in pounds, and  $k$  and  $a$  are constants.

In Table 1 we have tabulated values of  $k$  and  $a$  for the different fish sizes and depths of burst. The resulting empirical equations should prove useful in estimating relatively safe ranges for swimbladder fish.

Upon examining Figures 37, 38, and 39 it becomes apparent that the greater the depth of burst the greater the maximum horizontal range, regardless of fish size. This might seem to indicate that the fish-kill would be minimized if the charges were detonated at shallower depths, but the situation is not that simple. For one thing the shape of the contours must be taken into account. Figure 7 best illustrates this point. The maximum horizontal range,  $H_{\max}$ , is 905 feet at a depth of 15 feet. However, at shallower depths this range is reduced by more than half. At depths exceeding 15 feet it is less than  $0.25 H_{\max}$ . The other contours are not as sharply peaked, but the general shape is nevertheless maintained. Therefore, in Tables 2, 3, and 4 we have presented the charge weight, the depth of burst, DOB, the maximum horizontal range,  $H_{\max}$ , and  $D(H_{\max})$ , the depth at which  $H_{\max}$  is attained. From these tables we can see that in virtually every case the greater the DOB the closer  $D(H_{\max})$  is to the water surface. This is desirable for it increases the volume of 'safe water' under the contour. 'Safe water' denotes the region where kill probability is less than 10%. (It should be noted that for a given contour the volume of 'safe water' under the curve exceeds the volume of 'safe water' over the curve). However, as we have seen, the greater the DOB the greater is  $H_{\max}$ , so the two effects work against each other. Consequently, care must be exercised in deciding on shot geometries.

There is one other conclusion that can be drawn from a comparison of Tables 2, 3, and 4. In almost every instance,  $D(H_{\max})$  is greater for the larger fish. That is to say, the larger fish are safer at the shallower depths for a given charge size and depth of burst. To put it another way, the larger the fish the greater the volume of 'safe water' near the surface.

## CONCLUSIONS

There is a demonstrated need for quantitative predictions of fishkill due to underwater explosions. A computer program has been modified to generate such predictions in terms of probability contour plots. Calculations have been made for a wide range of charge weights, fish sizes, and depths of burst to encompass a great many practical situations. Empirical equations have been developed which relate maximum range to a function of the charge weight. Guidelines have been established for minimizing fish-kill.

TABLE 1. CONSTANTS IN THE FISH-KILL RANGE EQUATION

<u>FISH</u>	<u>DOB (FT)</u>	<u>COEFFICIENT K</u>	<u>EXPONENT a</u>
1-OZ	10	328	0.220
1-OZ	50	385	0.256
1-OZ	200	475	0.262
1-LB	10	174	0.264
1-LB	50	235	0.275
1-LB	200	272	0.299
30-LB	10	86	0.284
30-LB	50	131	0.314
30-LB	200	139	0.342

TABLE 2. CONTOUR PARAMETERS FOR A 30-LB FISH

<u>CHARGE</u> <u>(LBS)</u>	<u>DOB</u> <u>(FT)</u>	<u>H<sub>MAX</sub></u> <u>(FT)</u>	<u>D(H<sub>MAX</sub>)</u> <u>(FT)</u>
10	10	165	65
	50	260	25
	200	290	10
100	10	330	120
	50	590	70
	200	725	35
1000	10	630	135
	50	1130	100
	200	1555	60
10,000	10	1155	280
	50	2350	160
	200	3090	70

TABLE 3. CONTOUR PARAMETERS FOR A 1-LB FISH

<u>CHARGE</u> <u>(LBS)</u>	<u>DOB</u> <u>(FT)</u>	<u>H<sub>MAX</sub></u> <u>(FT)</u>	<u>D(H<sub>MAX</sub>)</u> <u>(FT)</u>
10	10	315	55
	50	425	25
	200	505	15
100	10	600	85
	50	865	50
	200	1225	30
1000	10	1130	125
	50	1655	50
	200	2390	25
10,000	10	1920	200
	50	2885	70
	200	4155	35

TABLE 4. CONTOUR PARAMETERS FOR A 1-OZ FISH

<u>CHARGE</u> <u>(LBS)</u>	<u>DOB</u> <u>(FT)</u>	<u>H<sub>MAX</sub></u> <u>(FT)</u>	<u>D(H<sub>MAX</sub>)</u> <u>(FT)</u>
10	10	530	40
	50	705	20
	200	905	15
100	10	985	60
	50	1235	15
	200	1540	30
1000	10	1465	60
	50	2255	25
	200	2870	10
10,000	10	2490	80
	50	4090	35
	200	5555	15

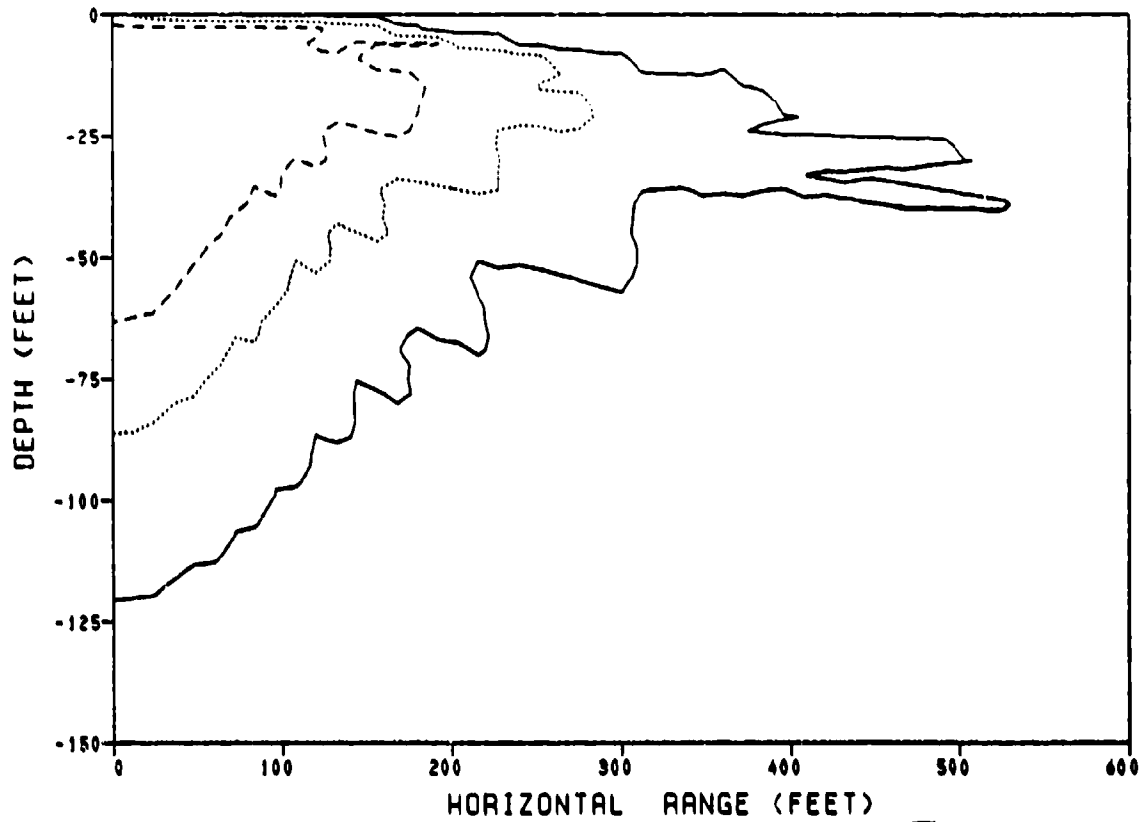


FIGURE 1. KILL PROBABILITY CONTOURS FOR 1-OZ FISH; 10-LB PENTOLITE, 10-FT DOB

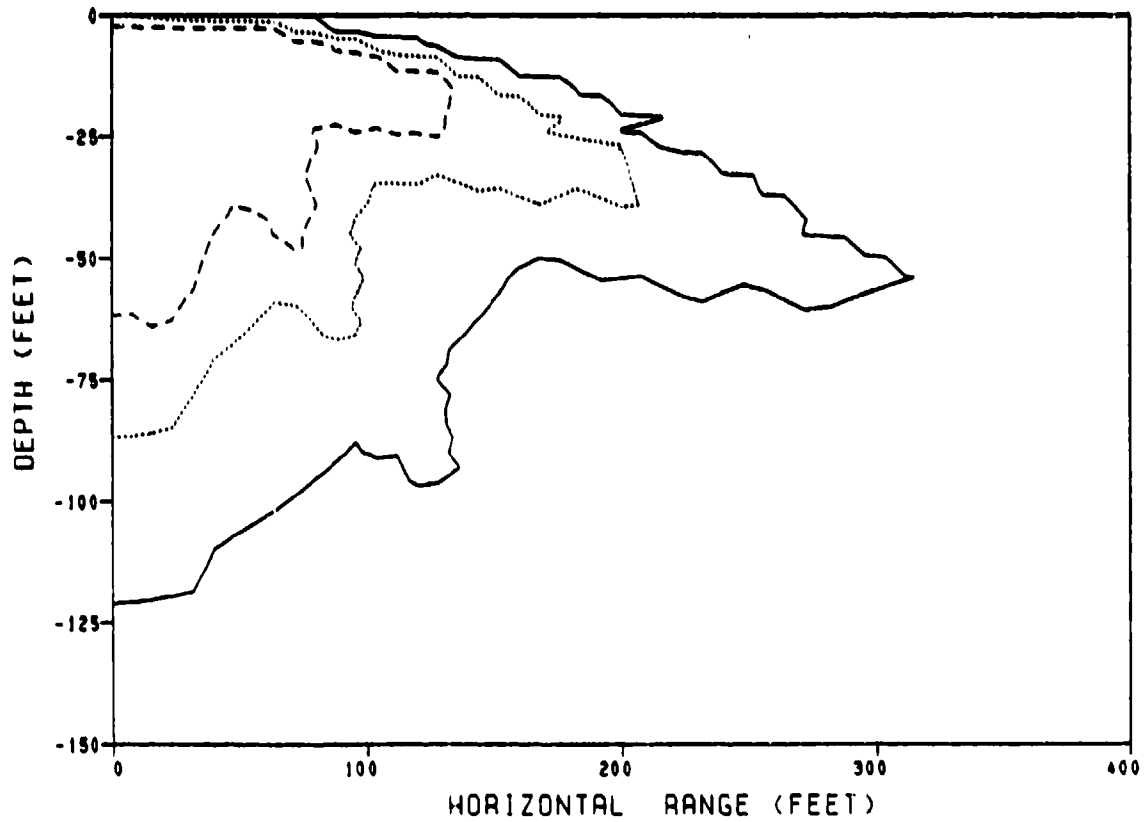


FIGURE 2. KILL PROBABILITY CONTOURS FOR 1-LB FISH; 10-LB PENTOLITE, 10-FT DOB

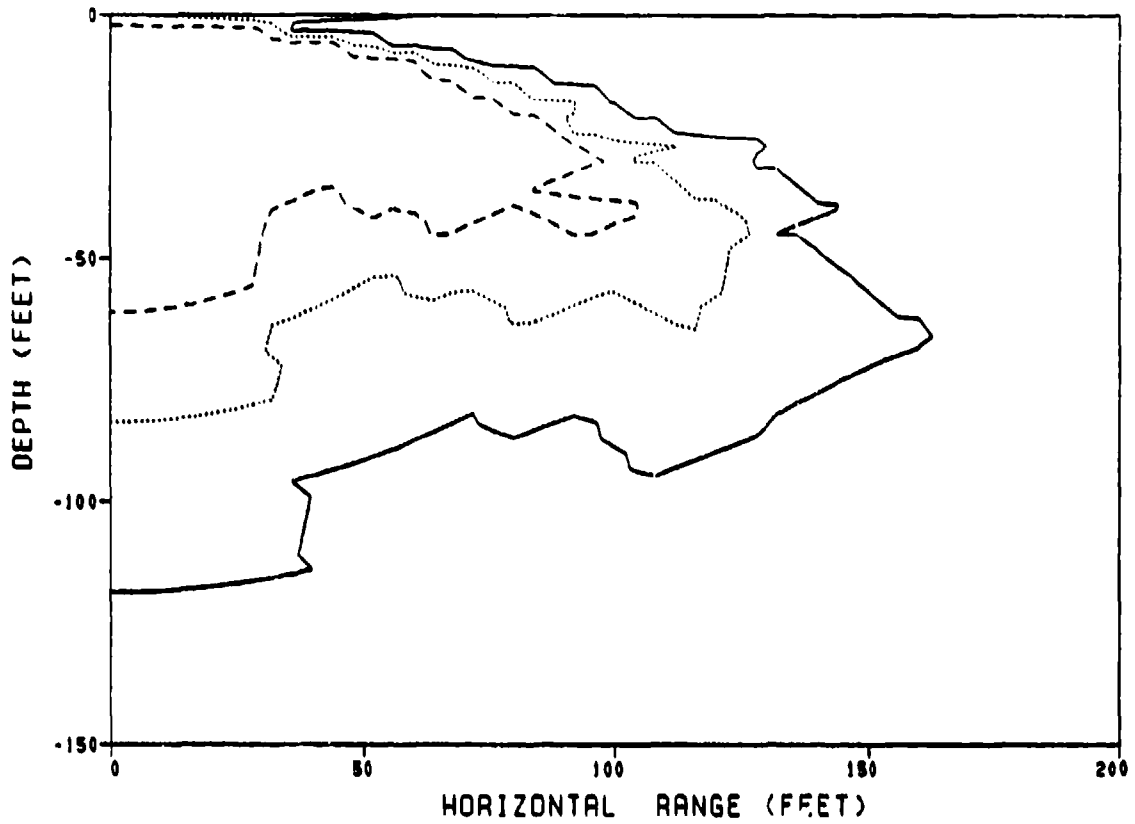


FIGURE 3. KILL PROBABILITY CONTOURS FOR 30-LB FISH; 10-LB PENTOLITE, 10-FT DOB

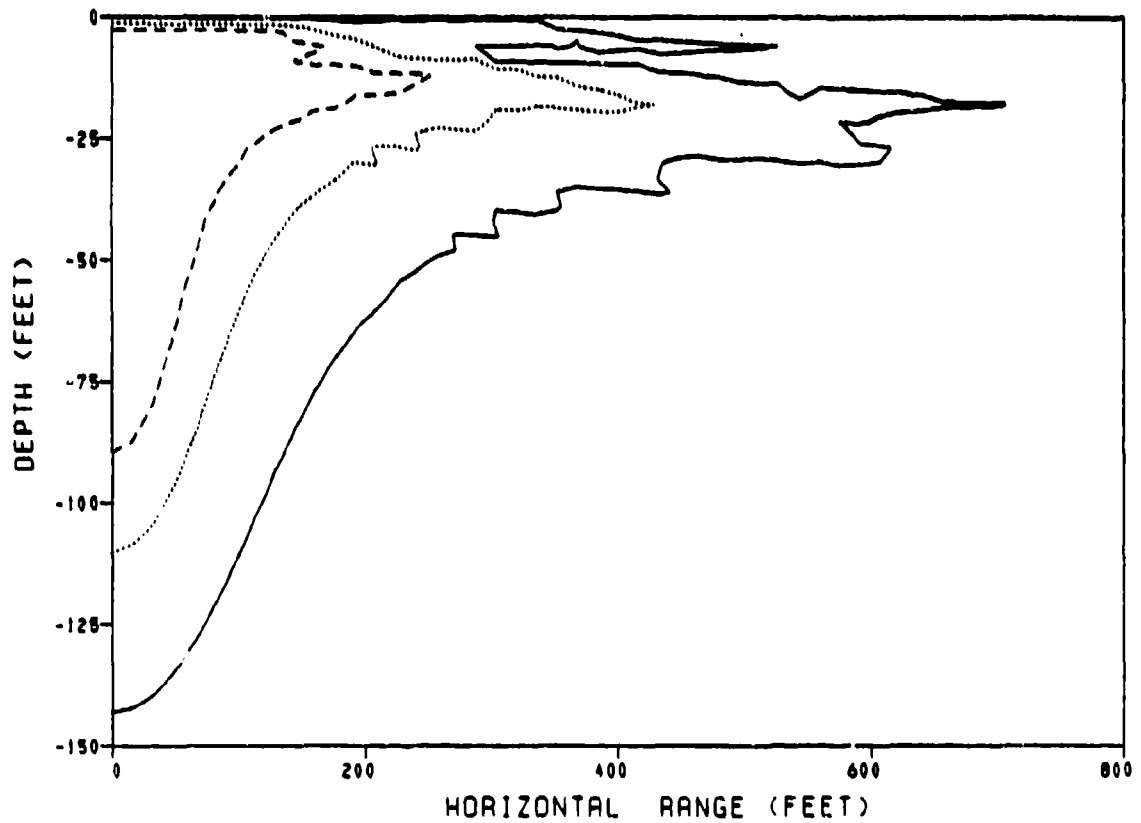


FIGURE 4. KILL PROBABILITY CONTOURS FOR 1-OZ FISH; 10-LB PENTOLITE, 50-FT DOB

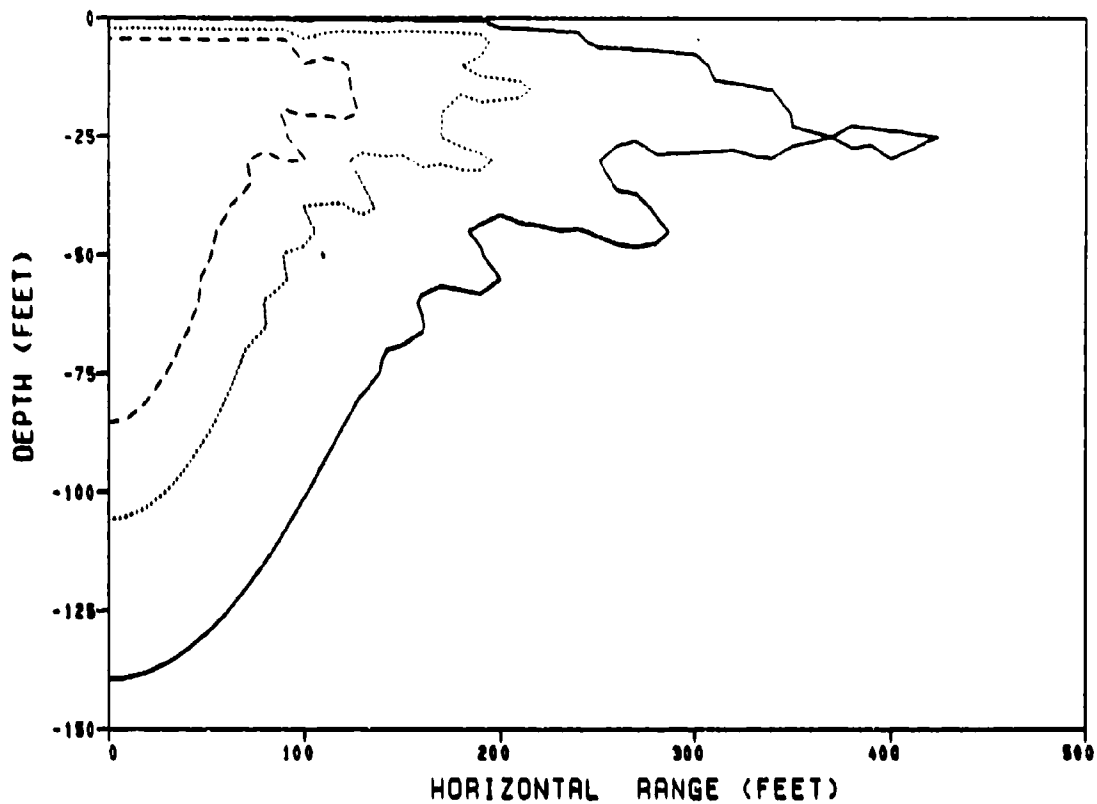


FIGURE 5. KILL PROBABILITY CONTOURS FOR 1-LB FISH; 10-LB PENTOLITE, 50-FT DOB

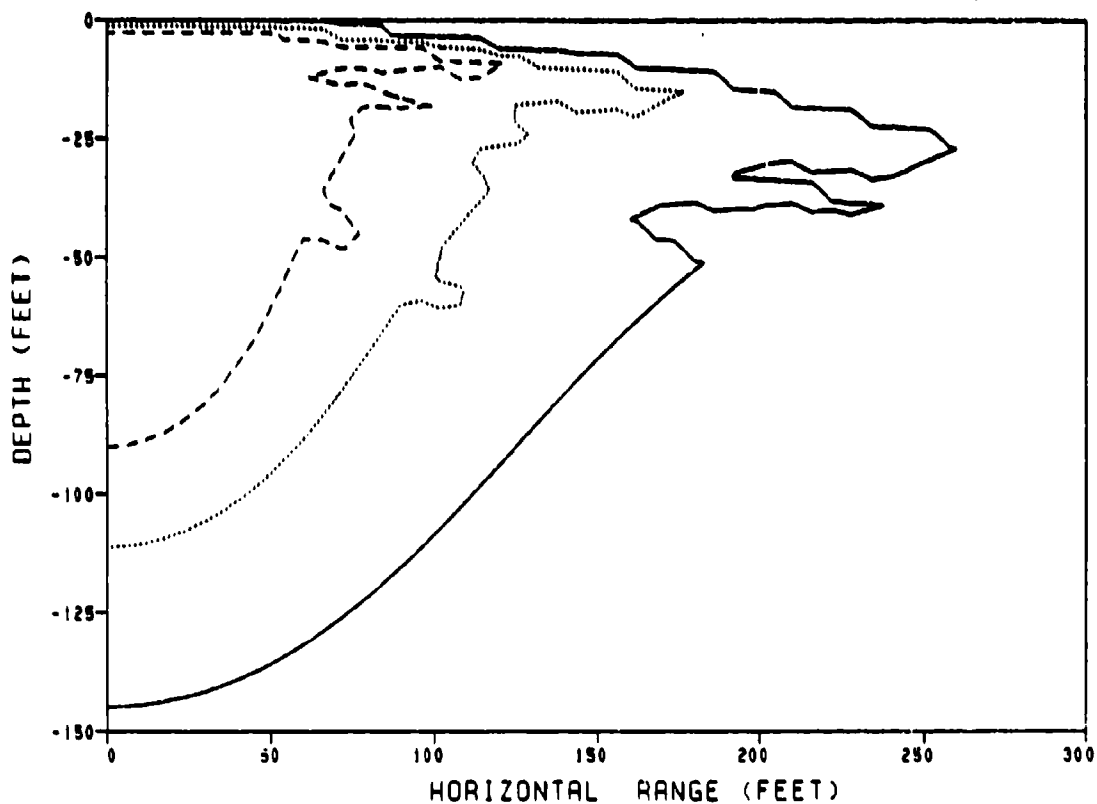


FIGURE 6. KILL PROBABILITY CONTOURS FOR 30-LB FISH; 10-LB PENTOLITE, 50-FT DOB

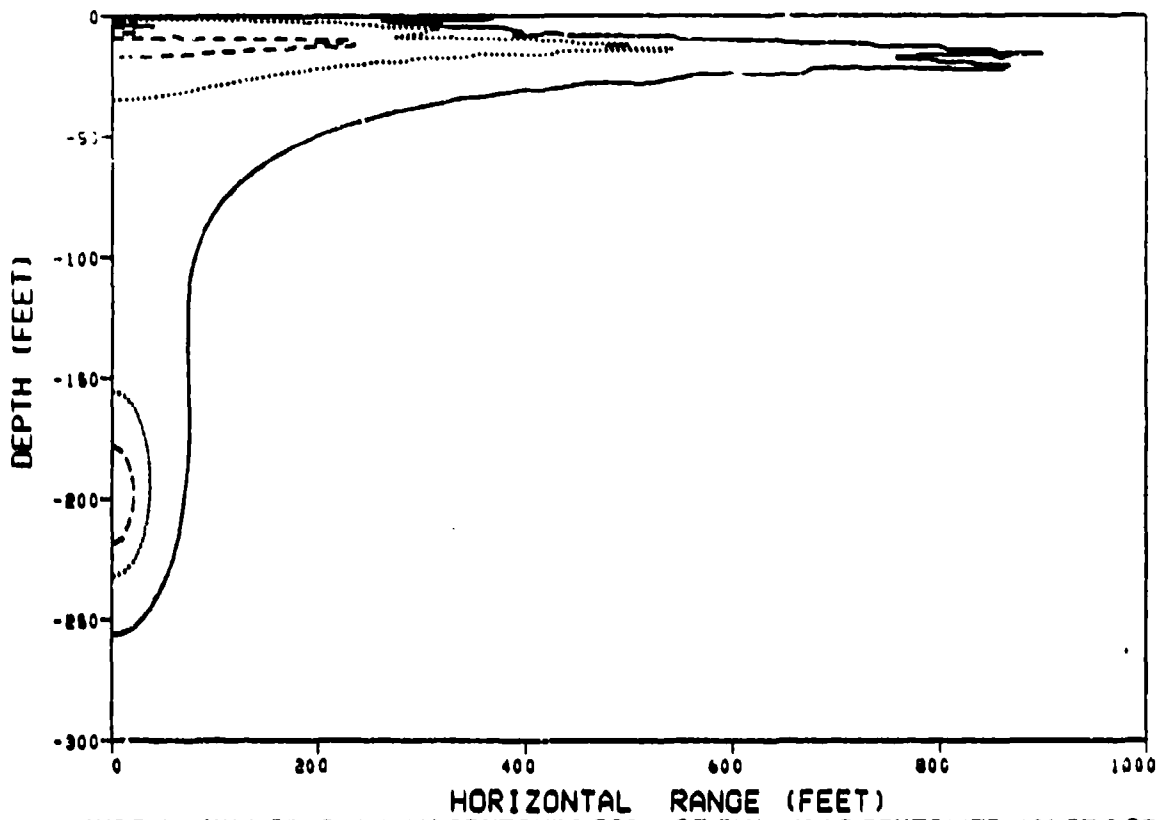


FIGURE 7. KILL PROBABILITY CONTOURS FOR 1-OZ FISH; 10-LB PENTOLITE, 200-FT DOB

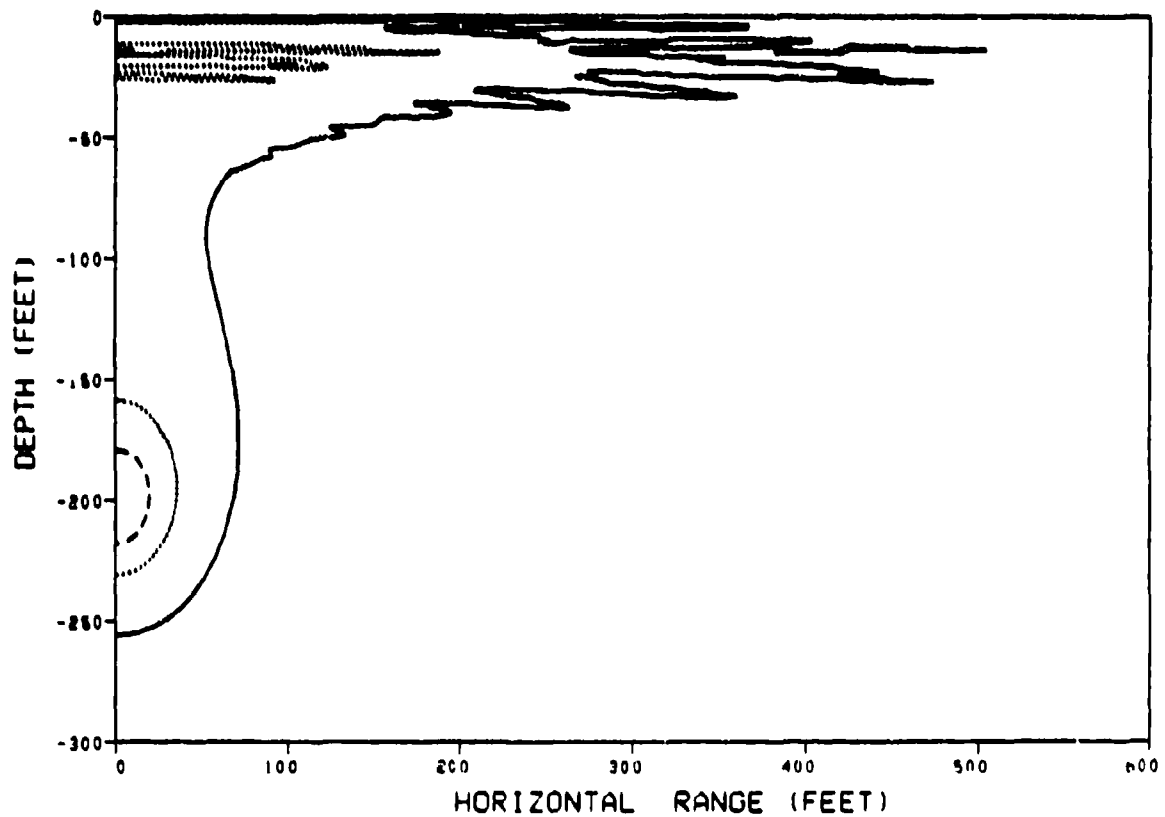


FIGURE 8. KILL PROBABILITY CONTOURS FOR 1-LB FISH; 10-LB PENTOLITE, 200-FT DOB

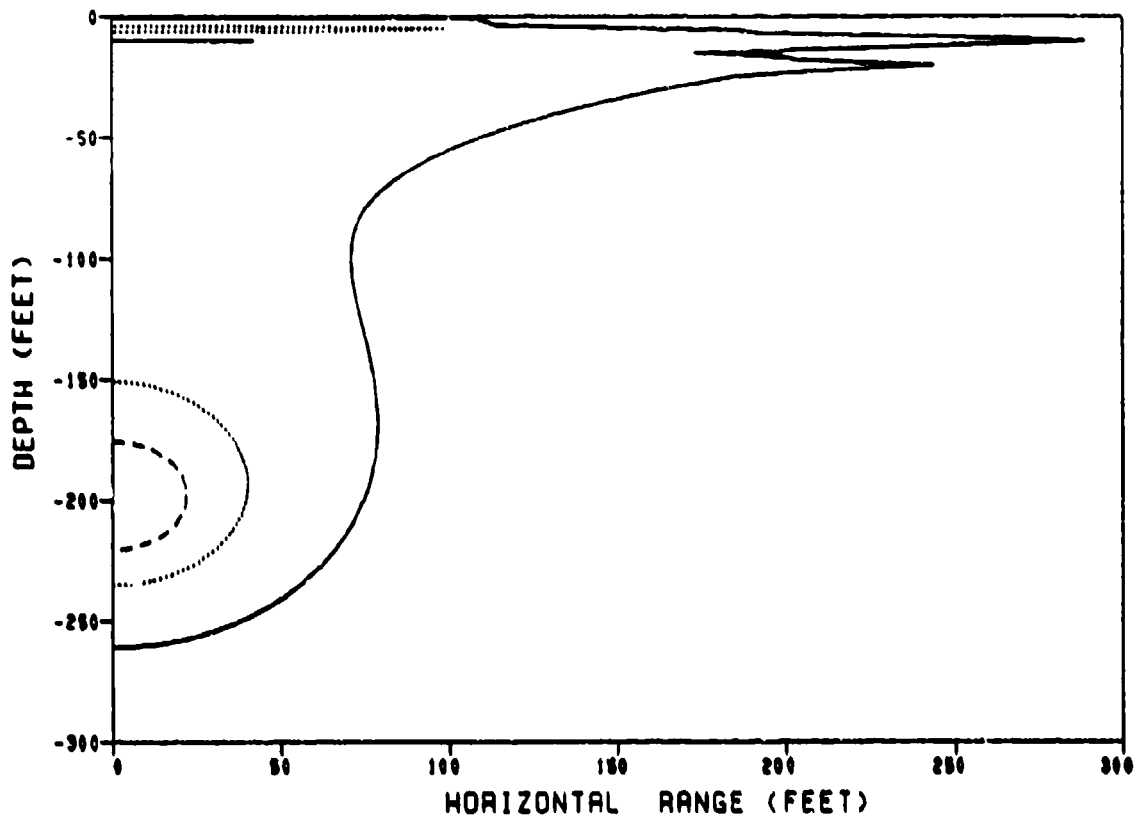


FIGURE 9. KILL PROBABILITY CONTOURS FOR 30-LB FISH; 10-LB PENTOLITE, 200-FT DOB

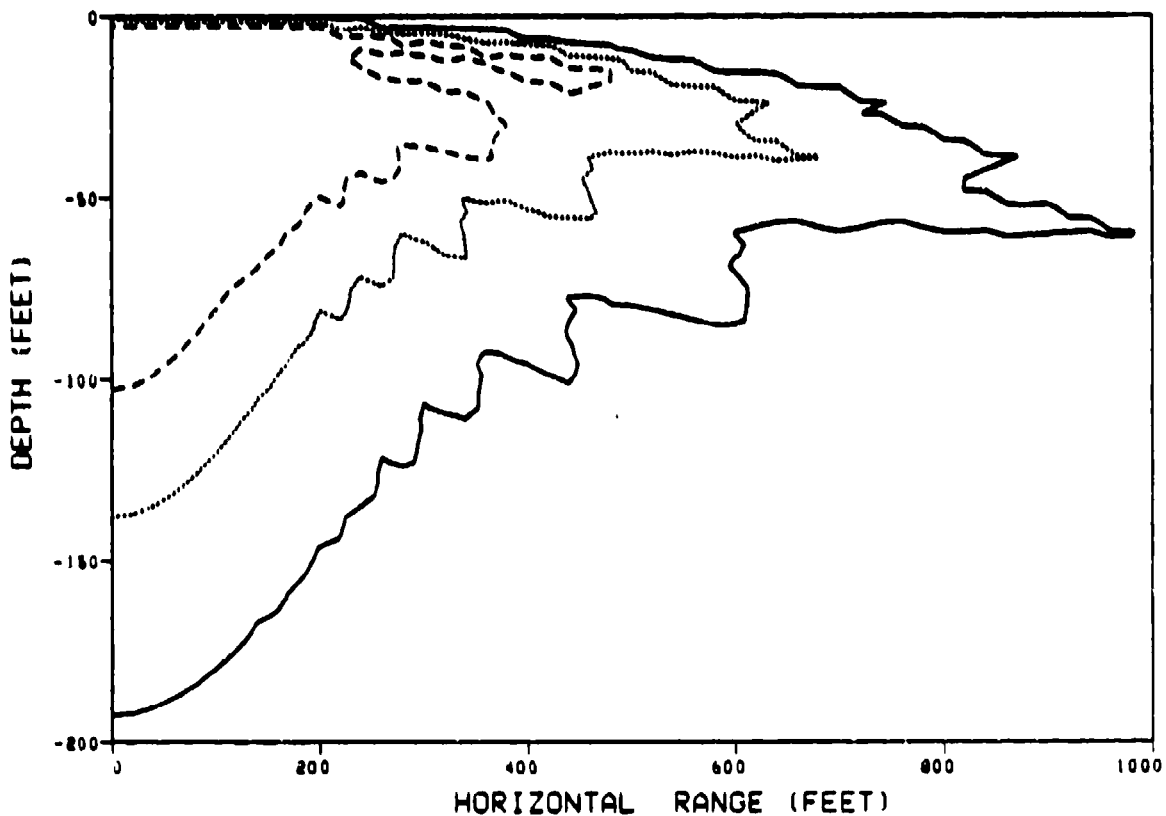


FIGURE 10. KILL PROBABILITY CONTOURS FOR 1-OZ FISH; 100-LB PENTOLITE, 10-FT DOB

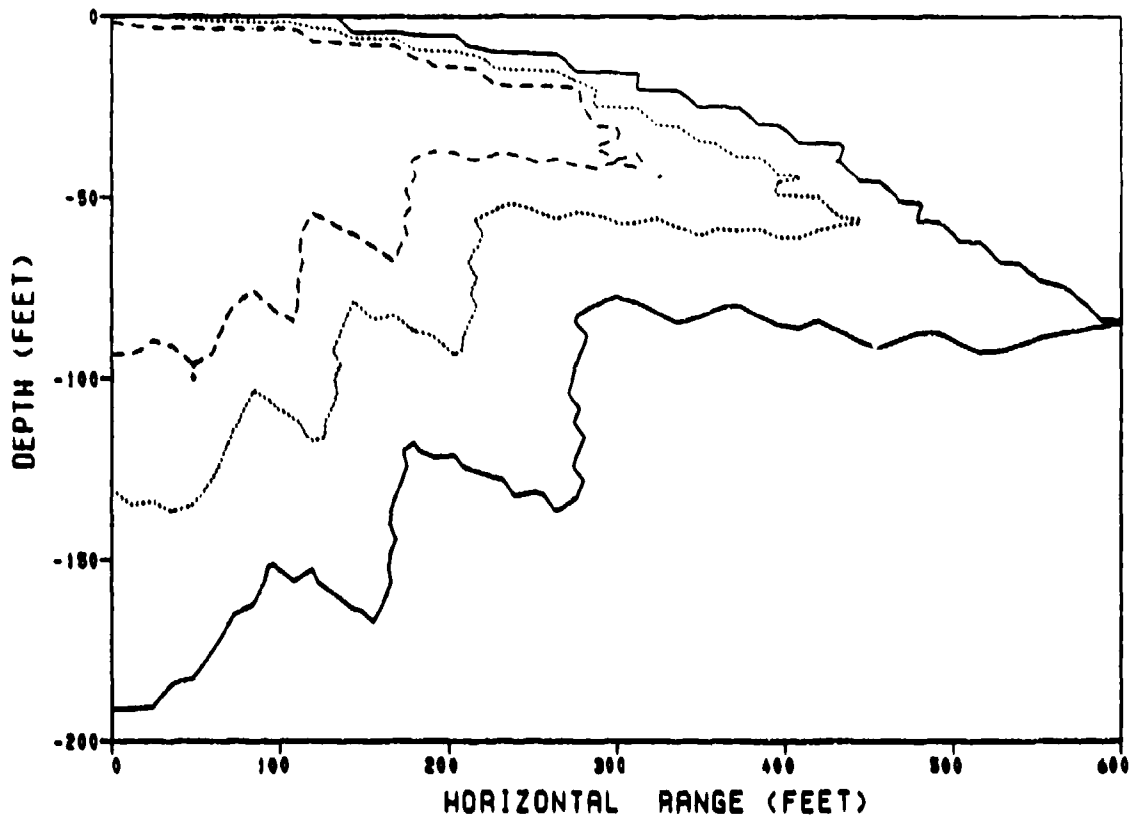


FIGURE 11. KILL PROBABILITY CONTOURS FOR 1-LB FISH; 100-LB PENTOLITE, 10-FT DOB

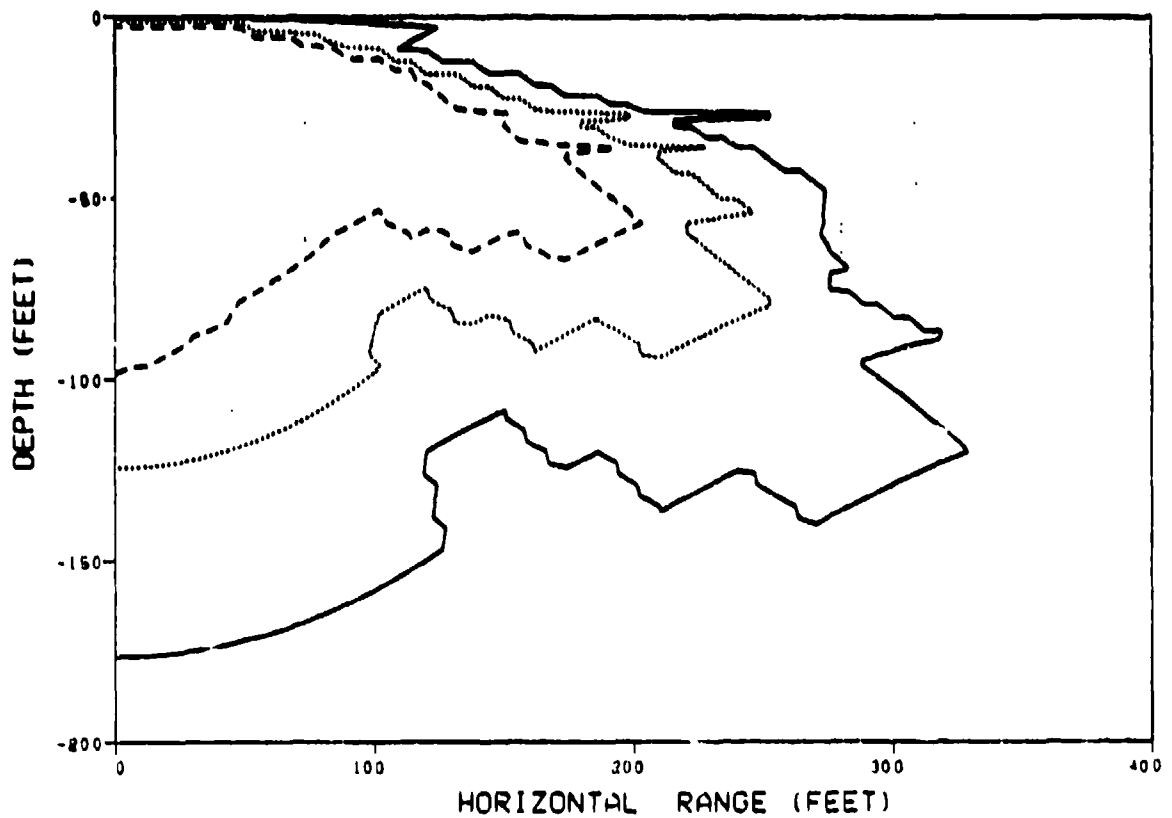


FIGURE 12. KILL PROBABILITY CONTOURS FOR 30-LB FISH; 100-LB PENTOLITE, 10-FT DOB

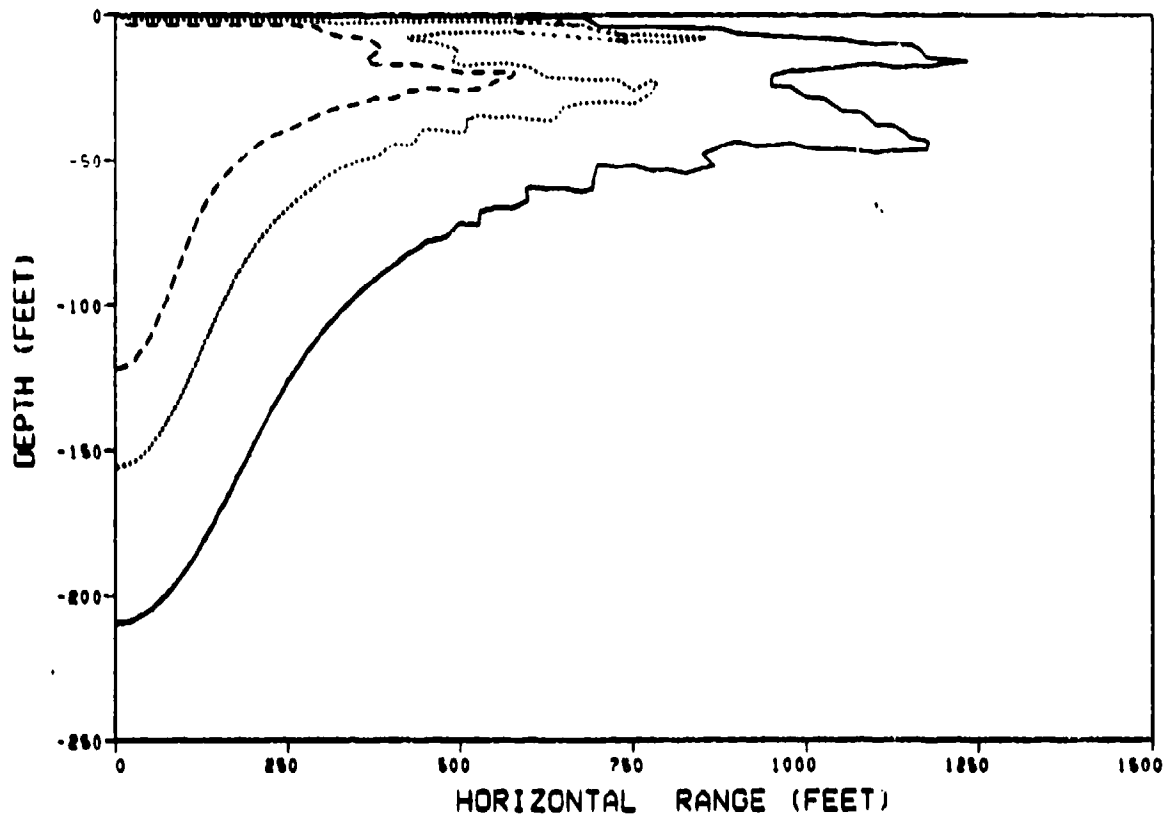


FIGURE 13. KILL PROBABILITY CONTOURS FOR 1-OZ FISH; 180-LB PENTOLITE, 60-FT DOB

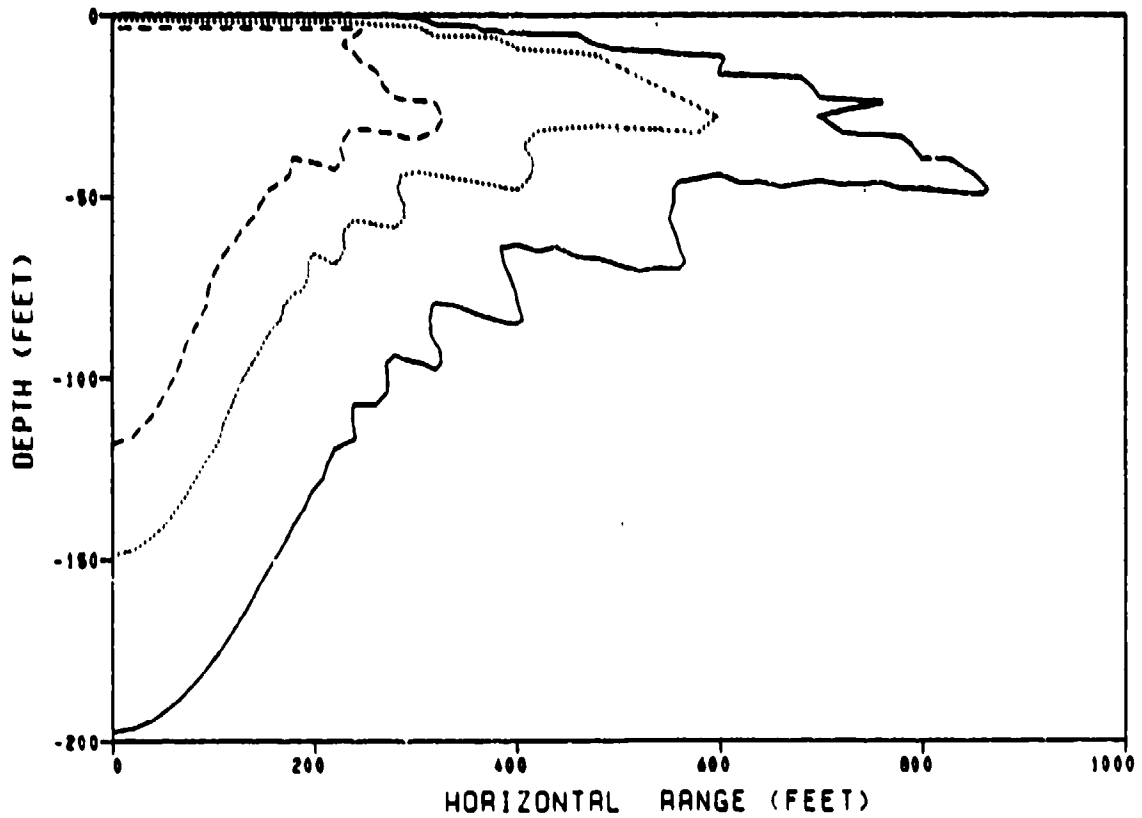


FIGURE 14. KILL PROBABILITY CONTOURS FOR 1-LB FISH; 100-LB PENTOLITE, 60-FT DOB

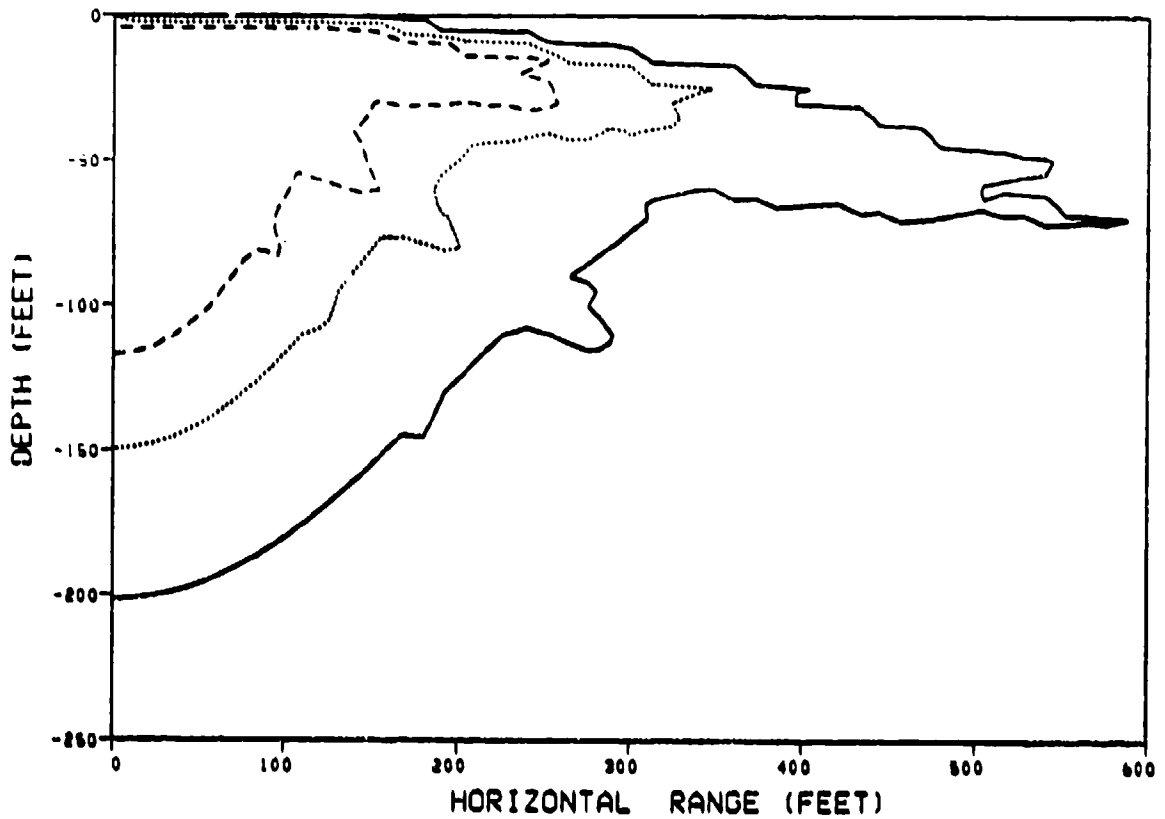


FIGURE 15. KILL PROBABILITY CONTOURS FOR 30-LB FISH; 100-LB PENTOLITE, 50-FT DOB

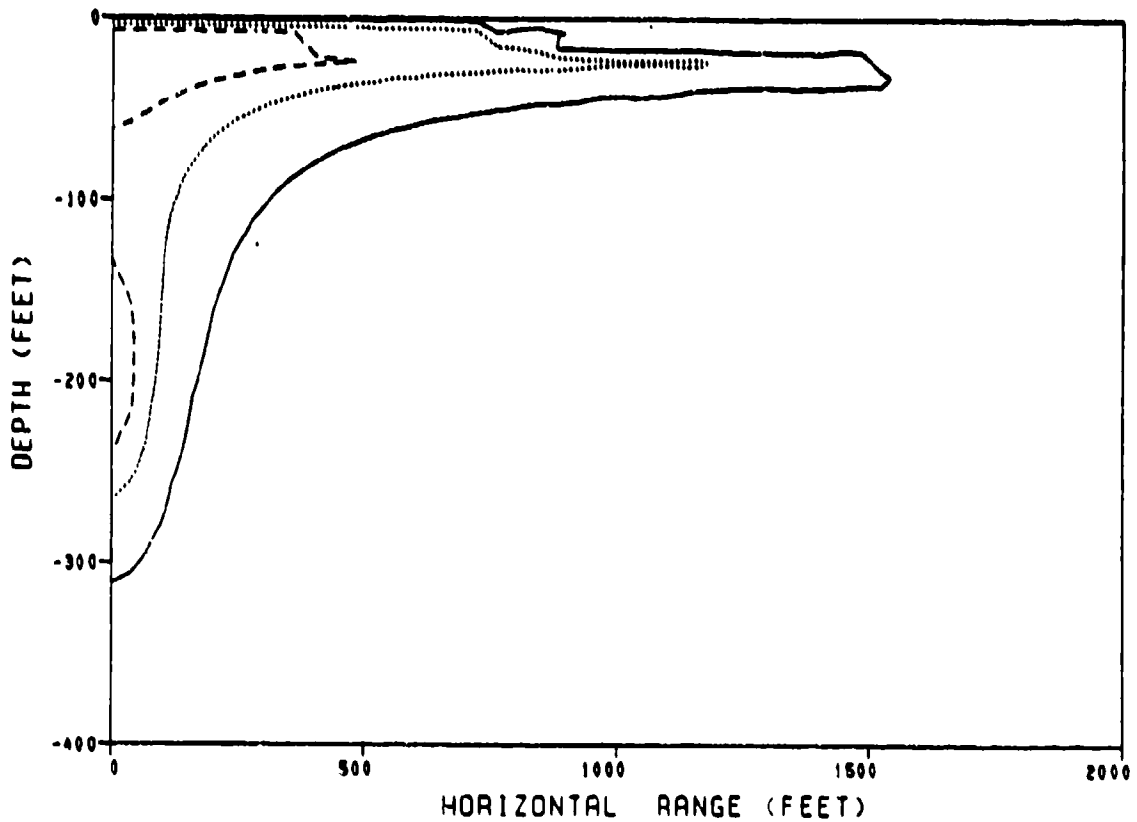


FIGURE 16. KILL PROBABILITY CONTOURS FOR 1-OZ FISH; 100-LB PENTOLITE, 200-FT DOB

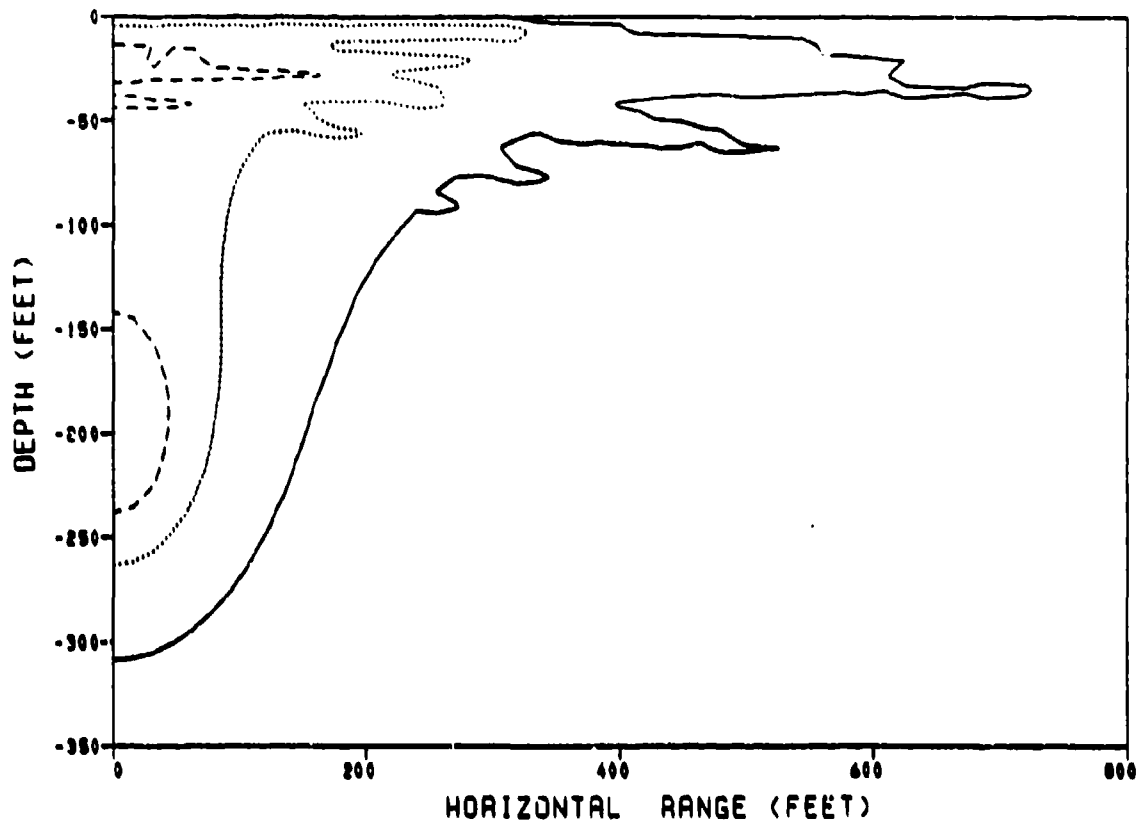


FIGURE 17. KILL PROBABILITY CONTOURS FOR 1-LB FISH; 100-LB PENTOLITE, 200-FT DOB

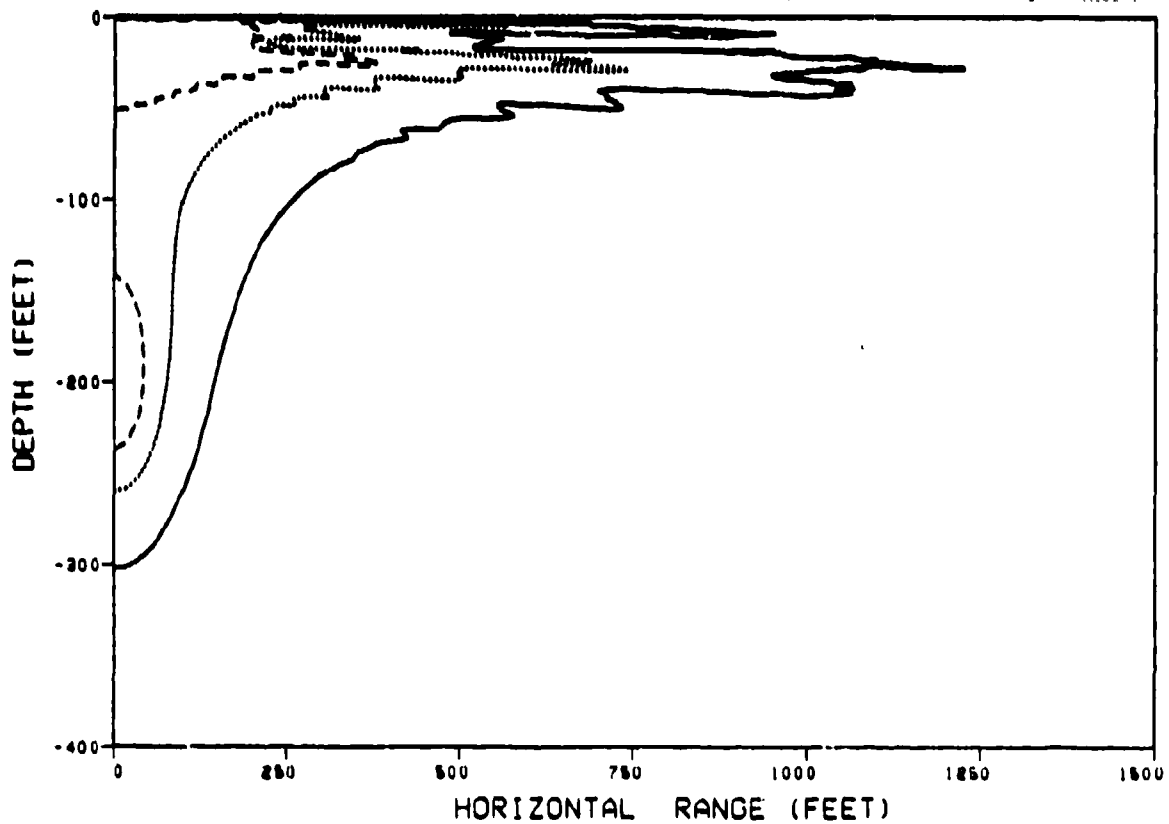


FIGURE 18. KILL PROBABILITY CONTOURS FOR 30-LB FISH; 100-LB PENTOLITE, 200-FT DOB

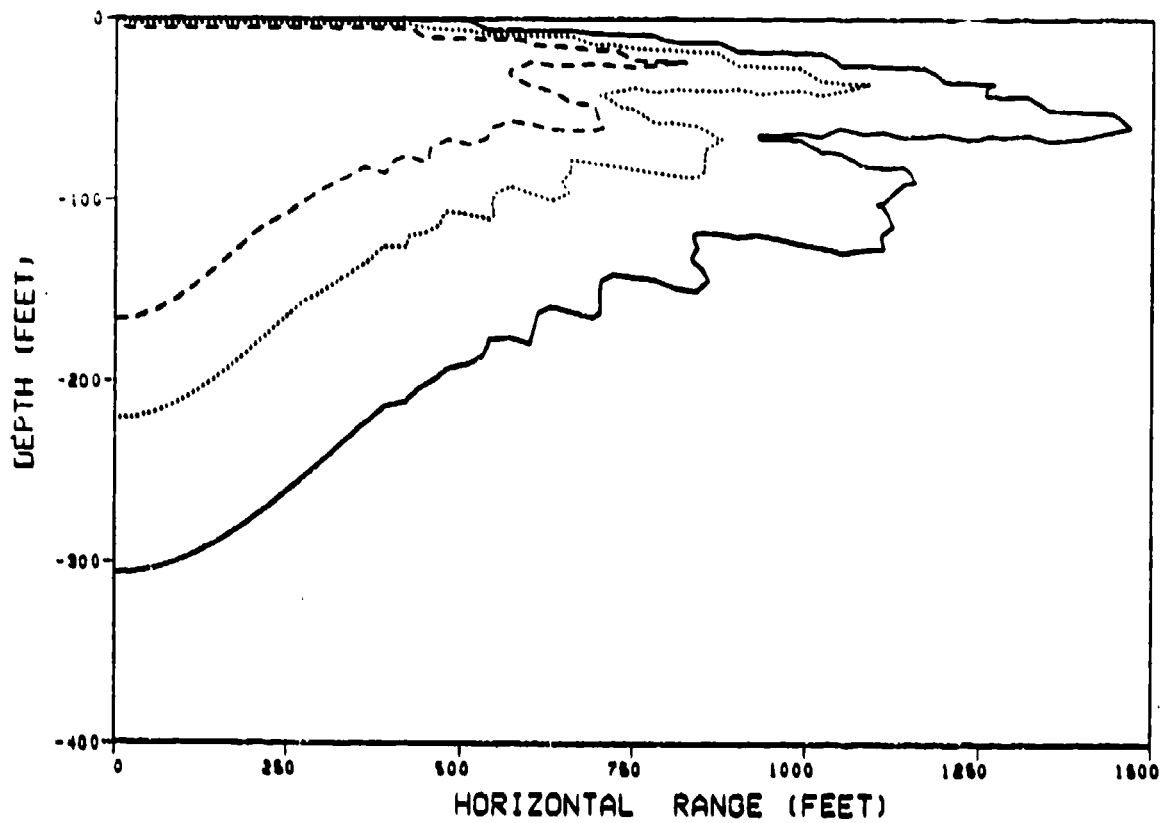


FIGURE 19. KILL PROBABILITY CONTOURS FOR 1-OZ FISH; 1000-LB PENTOLITE, 10-FT DOB

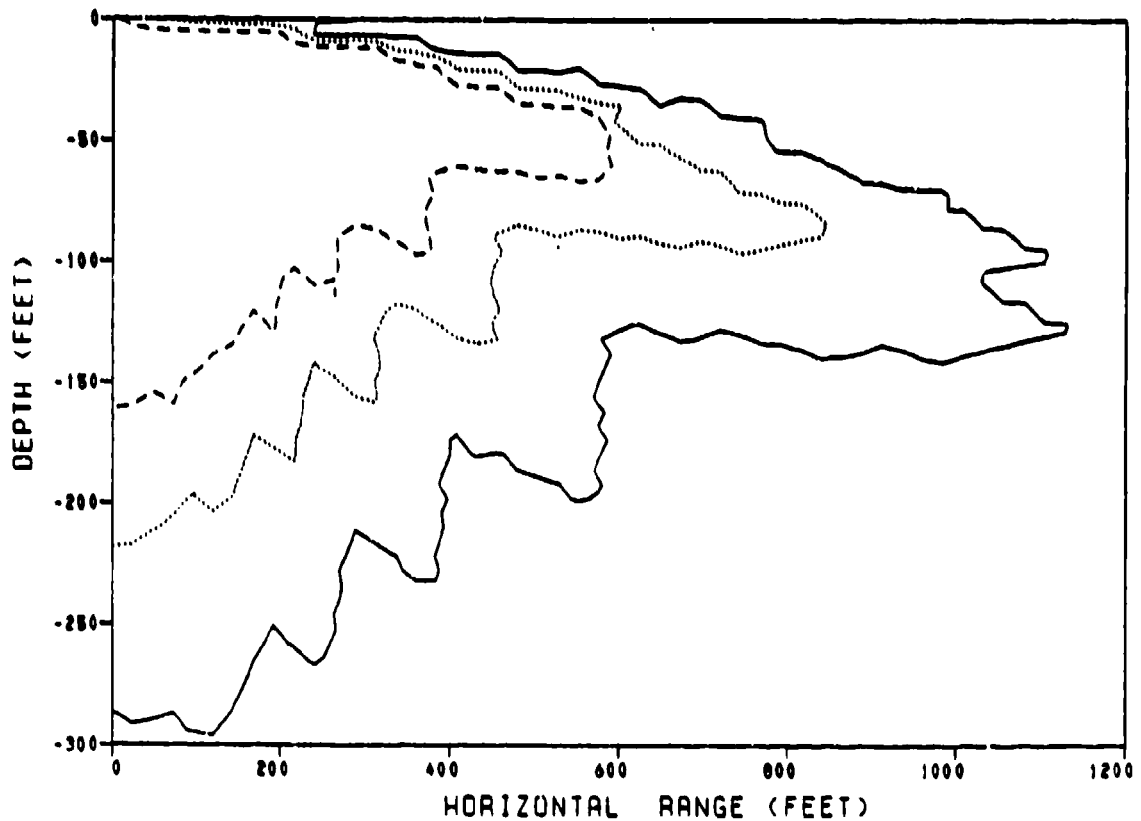


FIGURE 20. KILL PROBABILITY CONTOURS FOR 1-LB FISH; 1000-LB PENTOLITE, 10-FT DOB

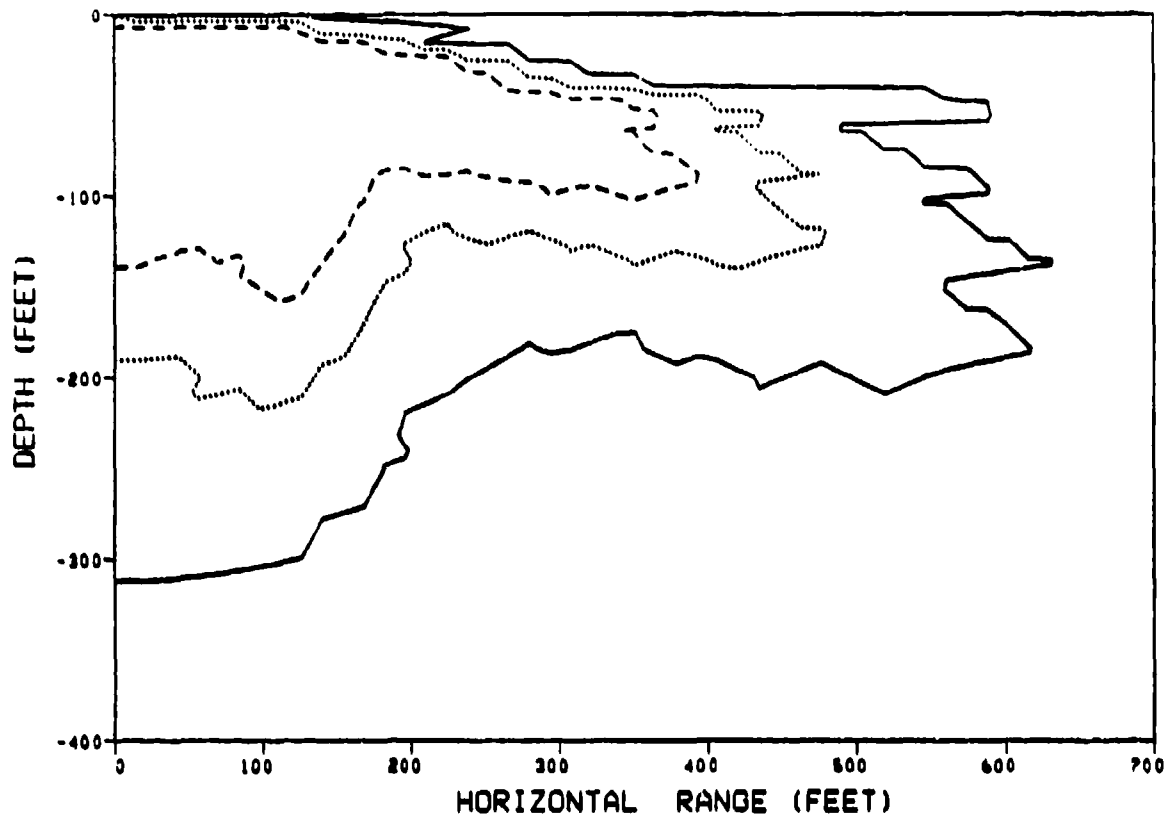


FIGURE 21. KILL PROBABILITY CONTOURS FOR 30-LB FISH; 1000-LB PENTOLITE, 10-FT DOB

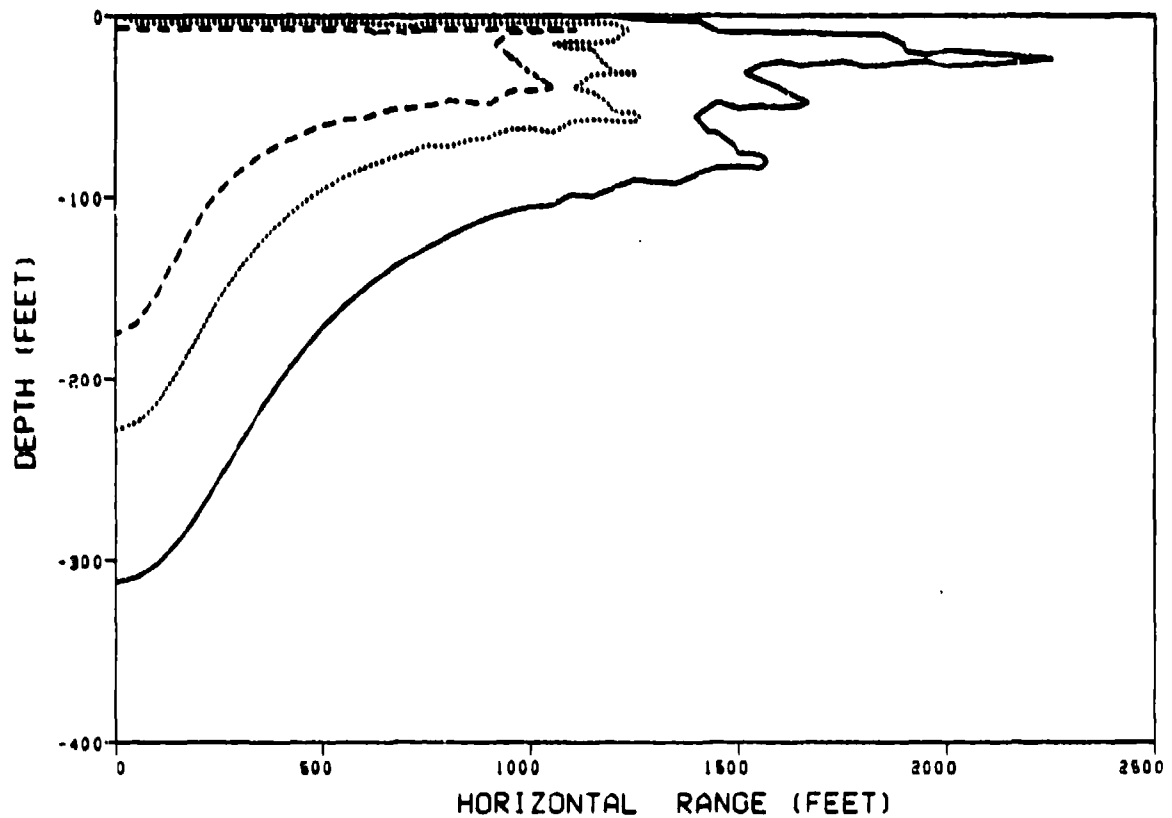


FIGURE 22. KILL PROBABILITY CONTOURS FOR 1-OZ FISH; 1000-LB PENTOLITE, 50-FT DOB

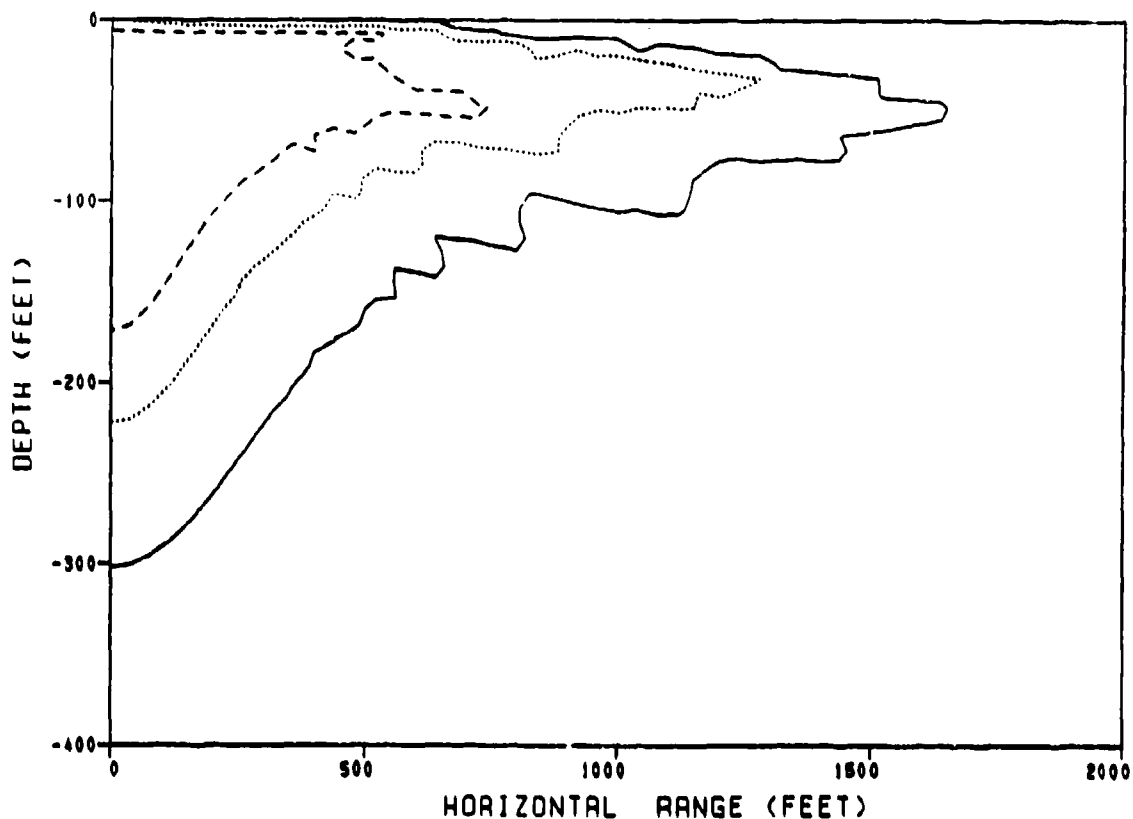


FIGURE 23. KILL PROBABILITY CONTOURS FOR 1-LB FISH; 1000-LB PENTOLITE, 50-FT DOB

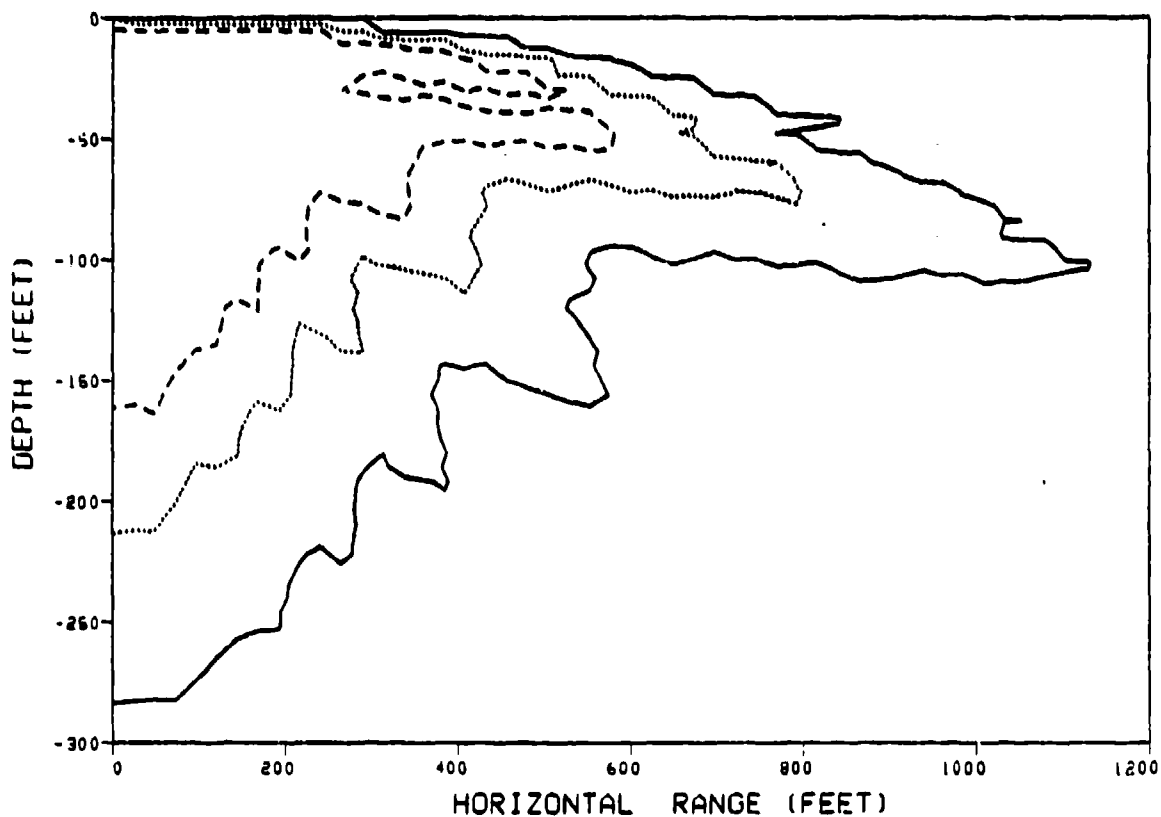


FIGURE 24. KILL PROBABILITY CONTOURS FOR 30-LB FISH; 1000-LB PENTOLITE, 50-FT DOB

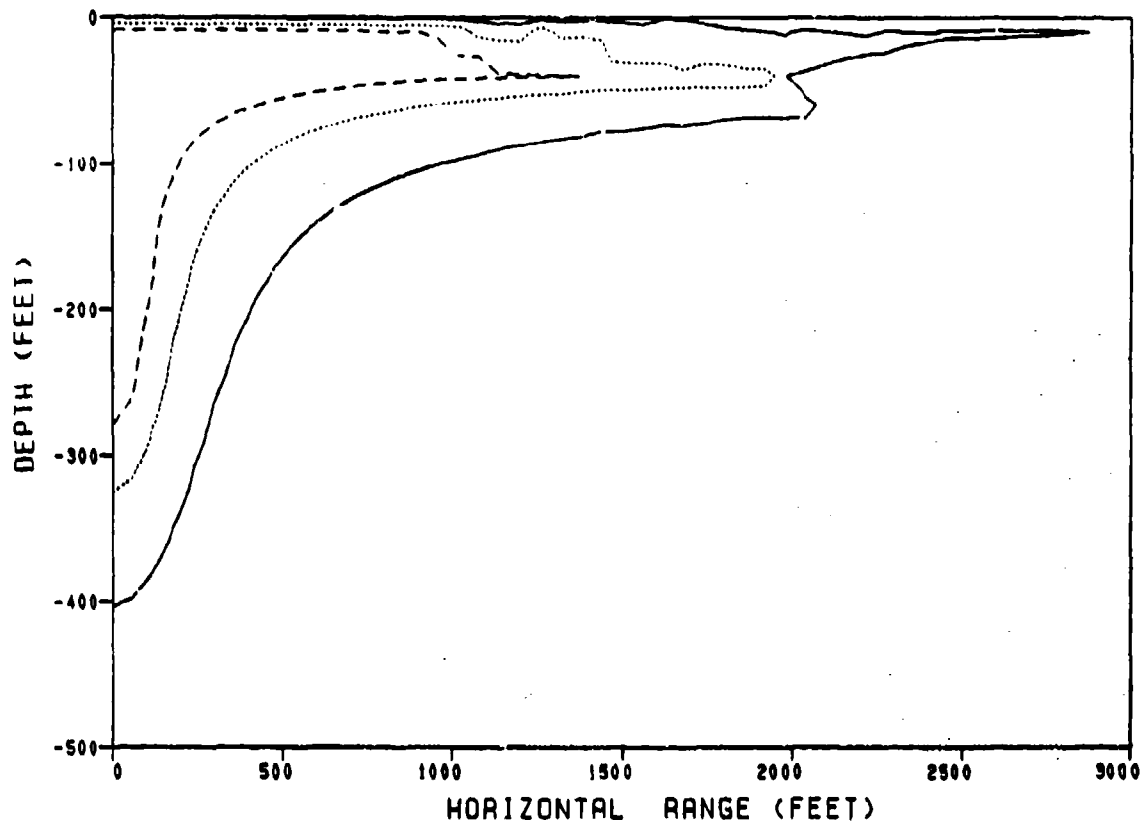


FIGURE 25. KILL PROBABILITY CONTOURS FOR 1-OZ FISH; 1000-LB PENTOLITE, 200-FT DOB

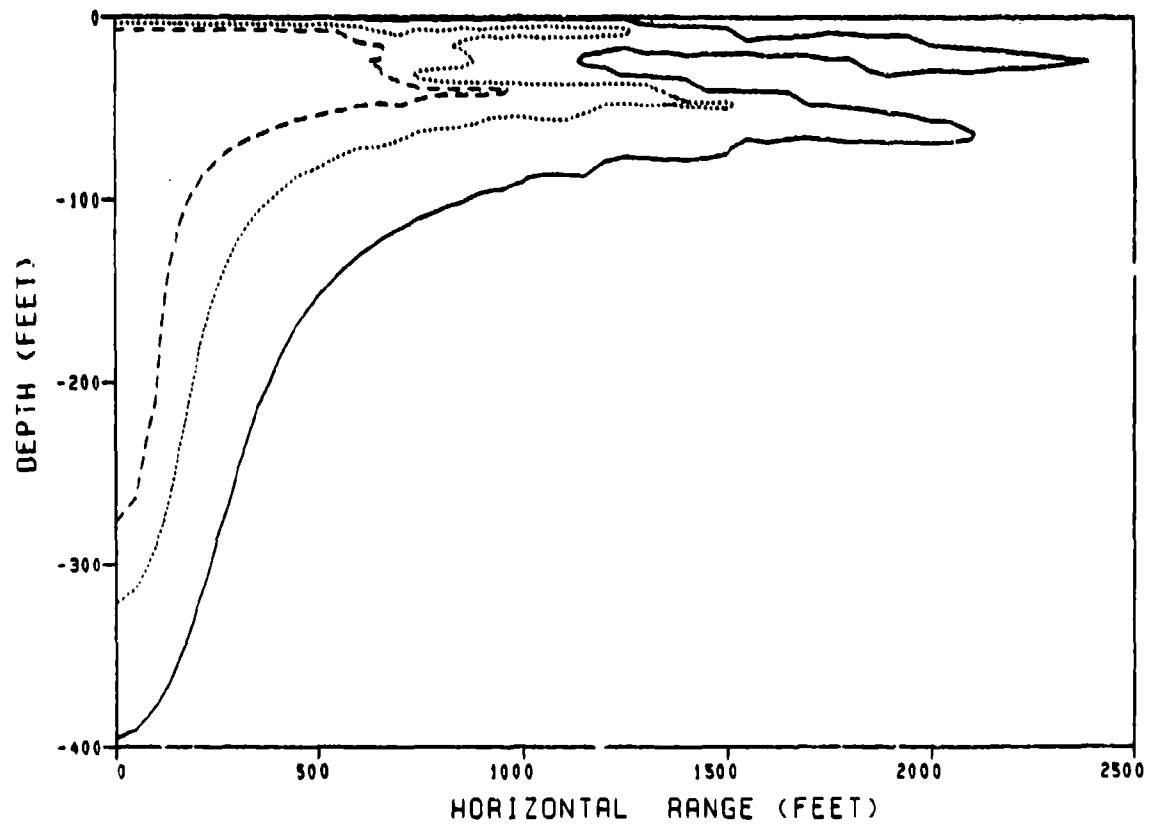


FIGURE 26. KILL PROBABILITY CONTOURS FOR 1-LB FISH; 1000-LB PENTOLITE, 200-FT DOB

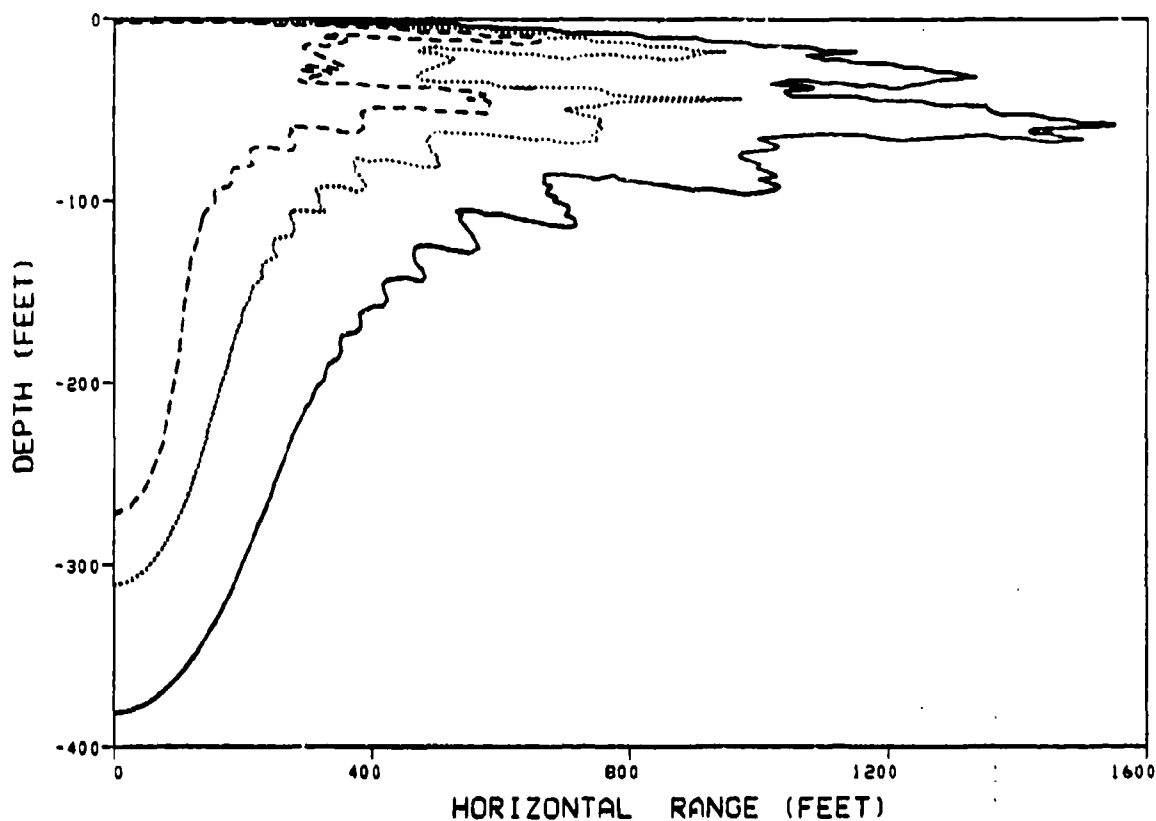


FIGURE 27. KILL PROBABILITY CONTOURS FOR 30-LB FISH; 1000-LB PENTOLITE, 200-FT DOB

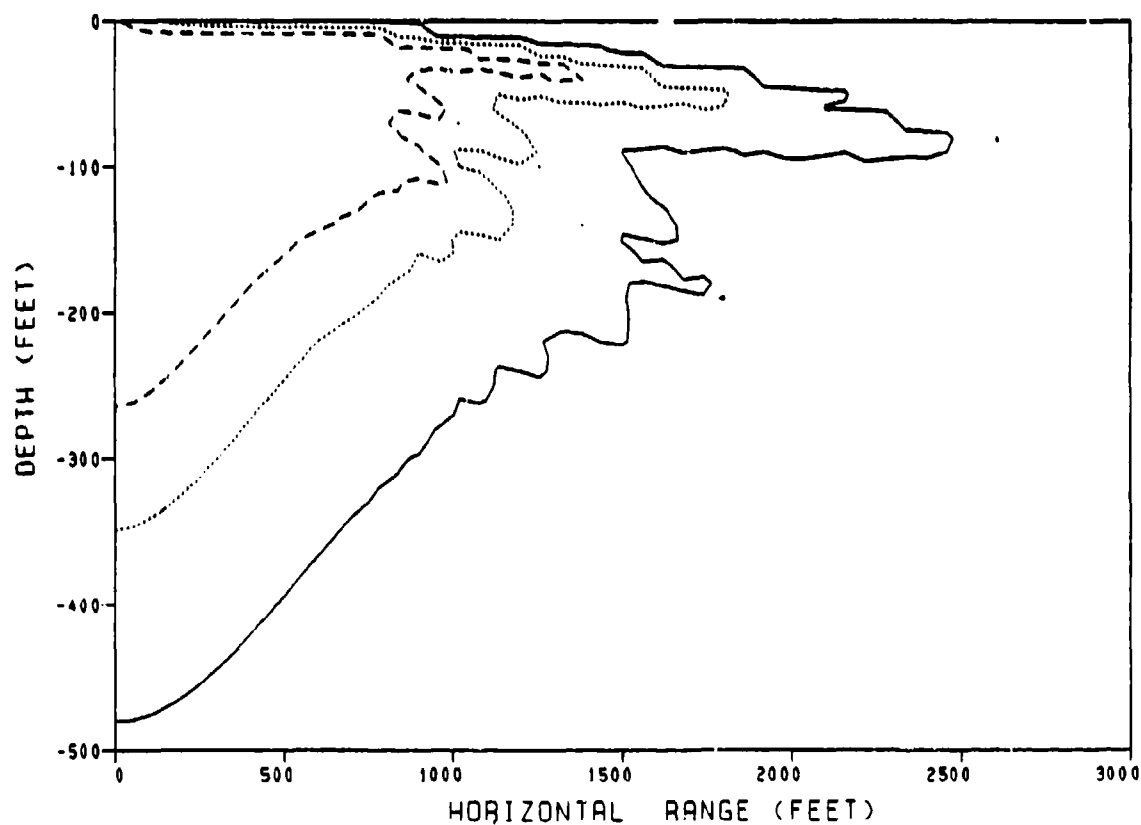


FIGURE 28. KILL PROBABILITY CONTOURS FOR 1-OZ FISH; 10,000-LB PENTOLITE, 10-FT DOB

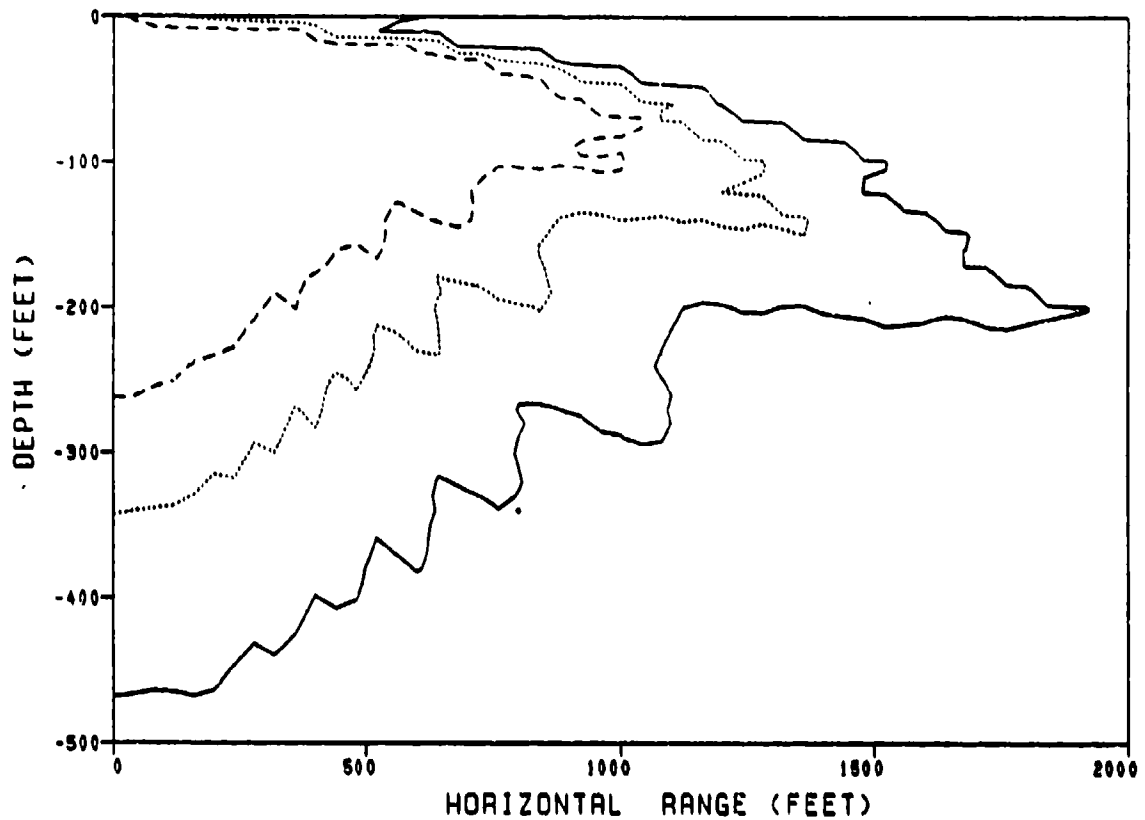


FIGURE 29. KILL PROBABILITY CONTOURS FOR 1-LB FISH; 10,000-LB PENTOLITE, 10-FT DOB

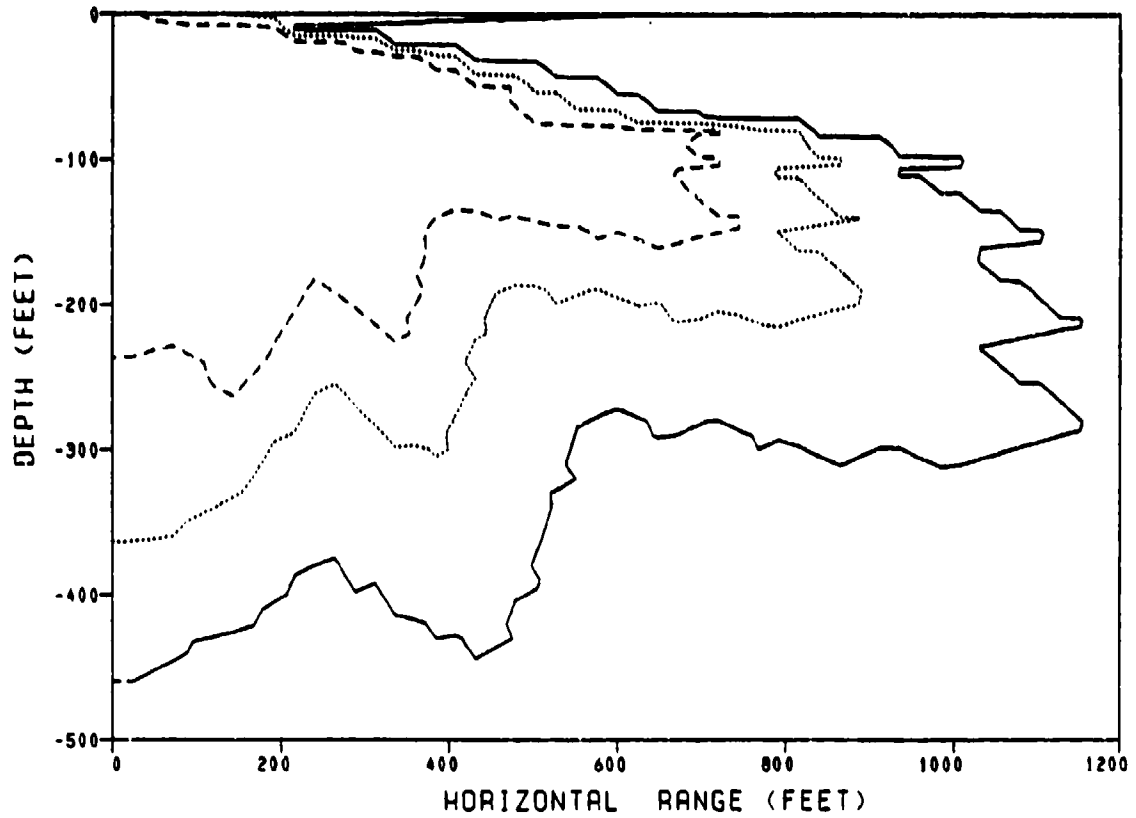


FIGURE 30. KILL PROBABILITY CONTOURS FOR 30-LB FISH; 10,000-LB PENTOLITE, 10-FT DOB

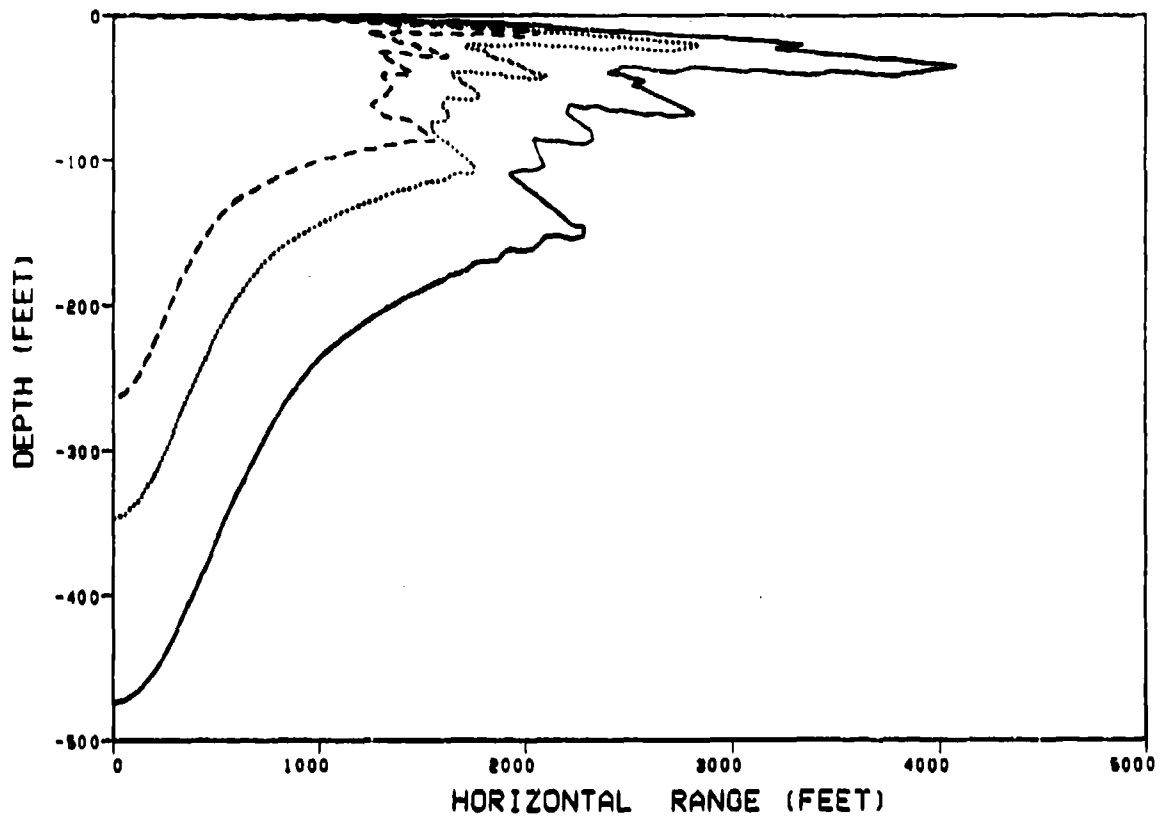


FIGURE 31. KILL PROBABILITY CONTOURS FOR 1-OZ FISH; 10,000-LB PENTOLITE, 50-FT DOB

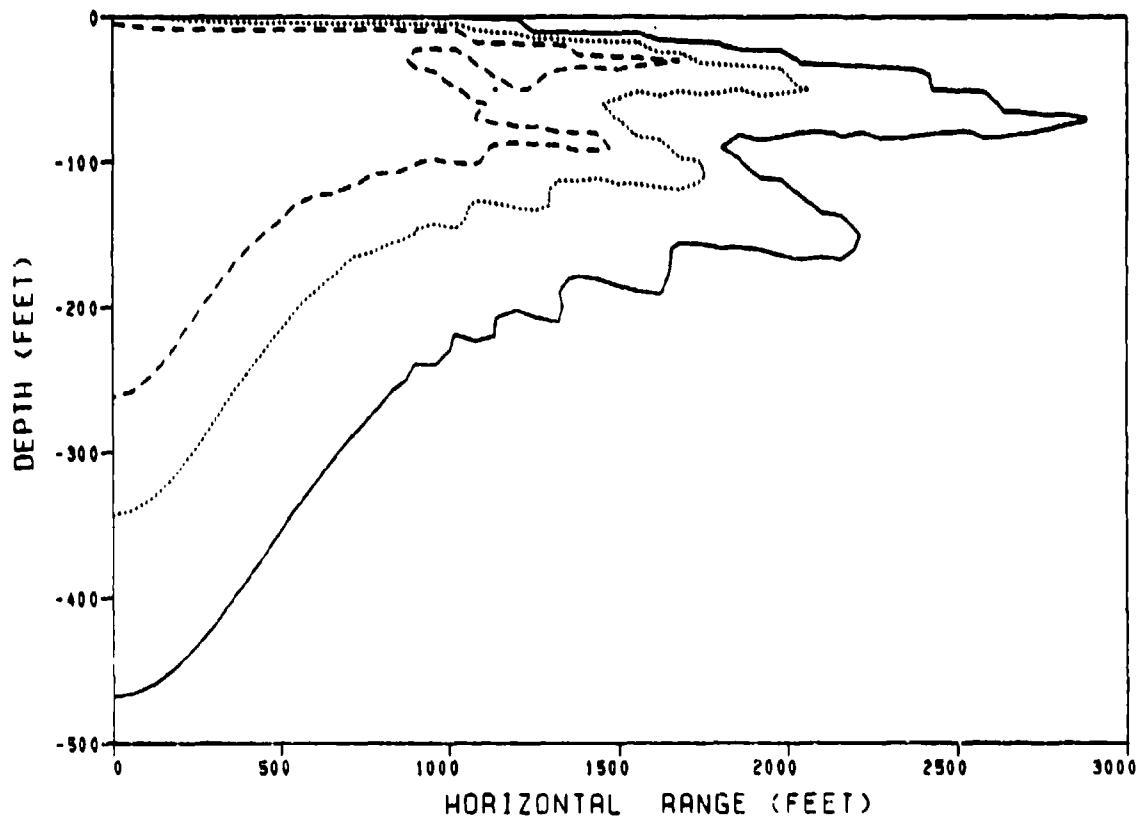


FIGURE 32. KILL PROBABILITY CONTOURS FOR 1-LB FISH; 10,000-LB PENTOLITE, 50-FT DOB

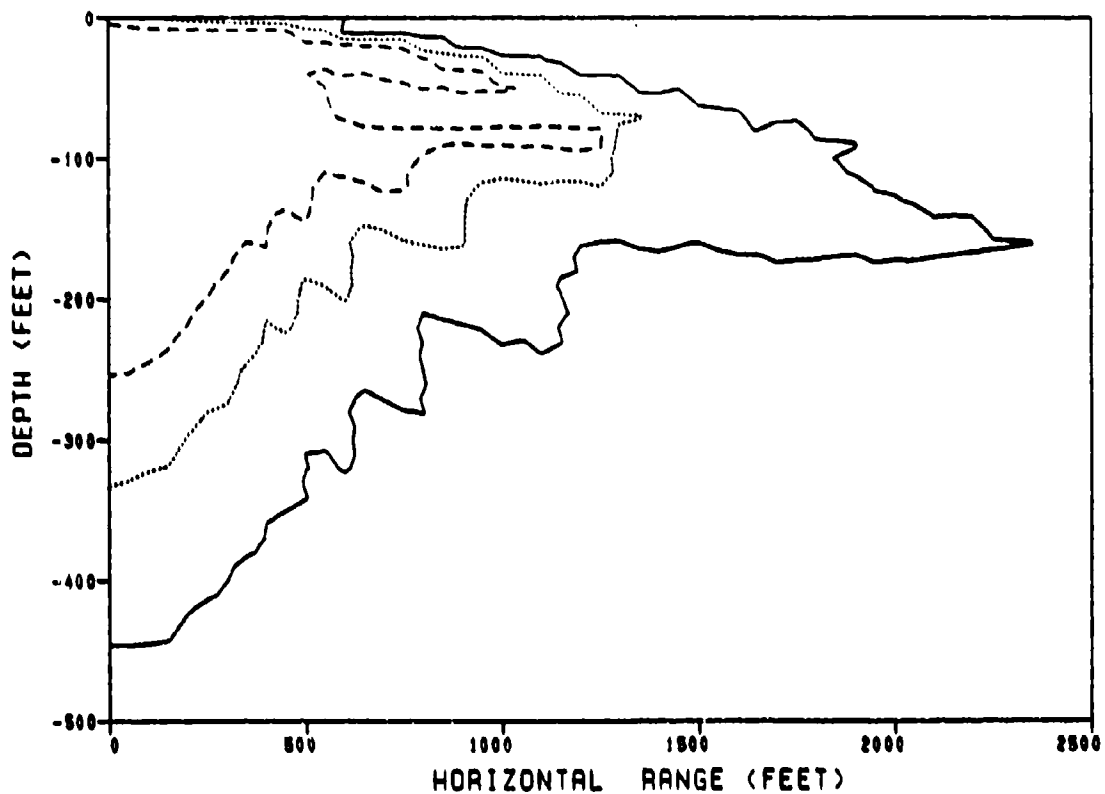


FIGURE 33. KILL PROBABILITY CONTOURS FOR 30-LB FISH; 10,000-LB PENTOLITE, 50-FT DOB

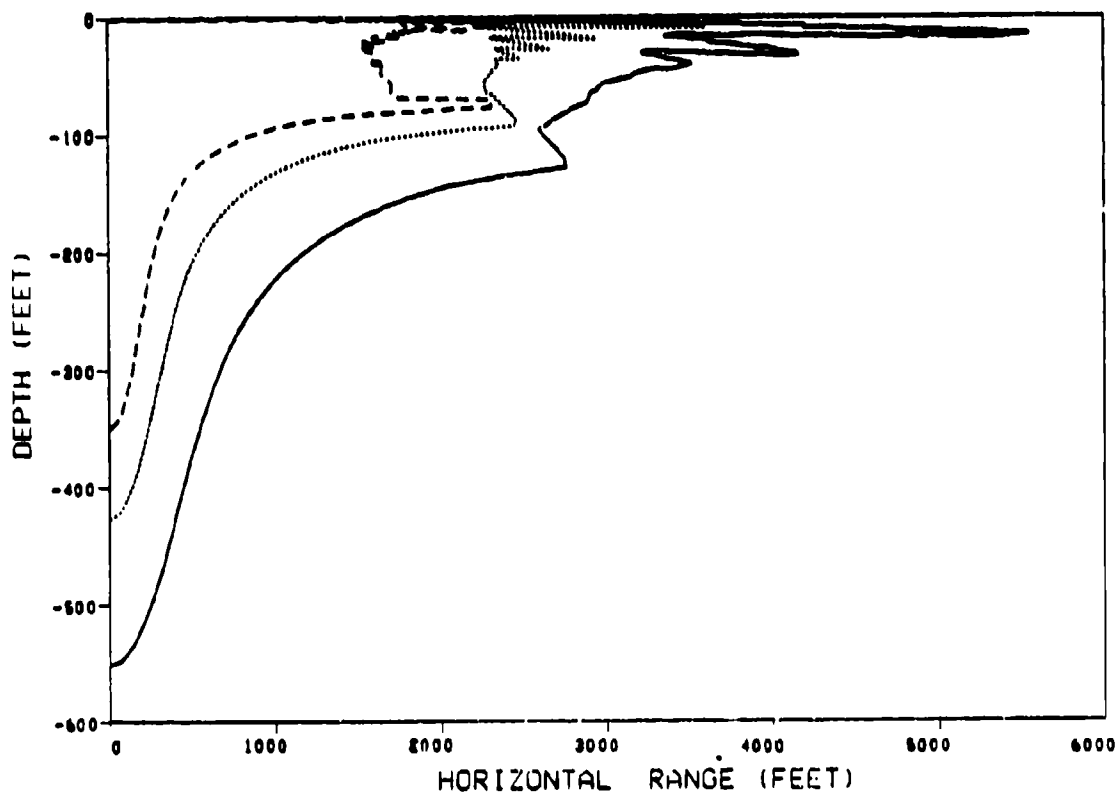


FIGURE 34. KILL PROBABILITY CONTOURS FOR 1-OZ FISH; 10,000-LB PENTOLITE, 200-FT DOB

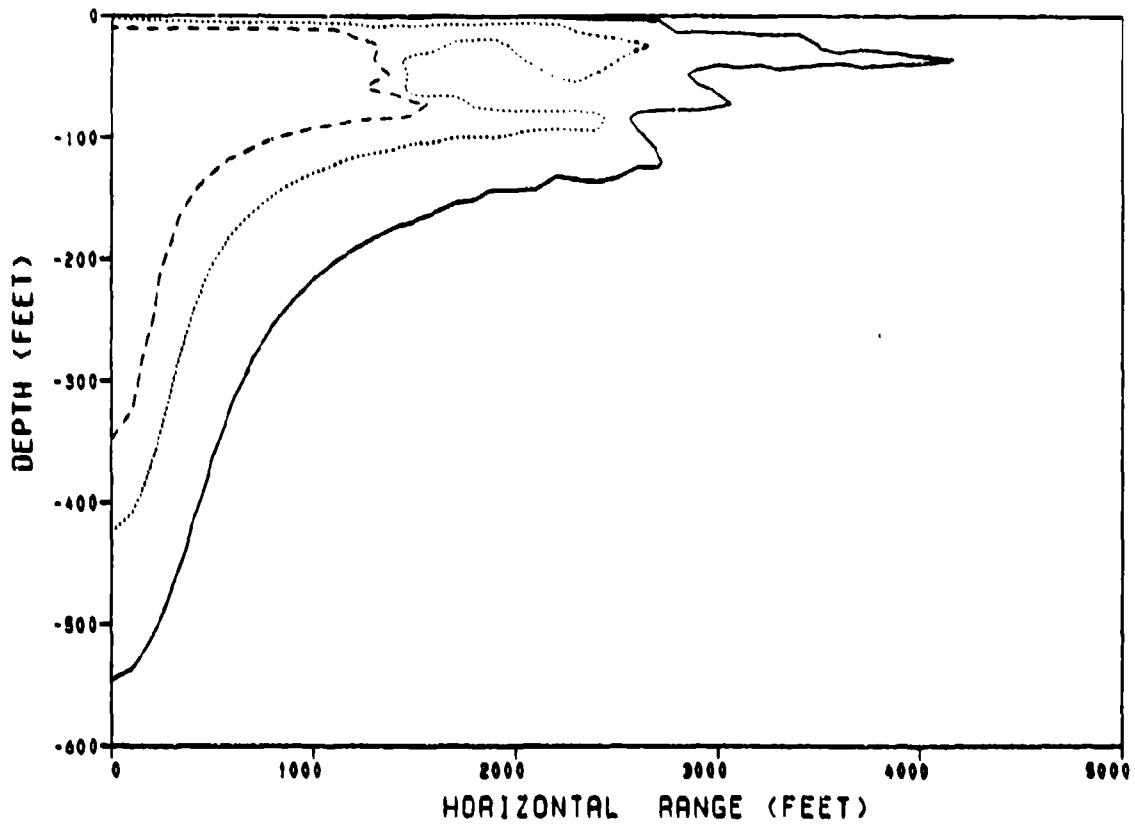


FIGURE 35. KILL PROBABILITY CONTOURS FOR 1-LB FISH; 10,000-LB PENTOLITE, 200-FT DOB

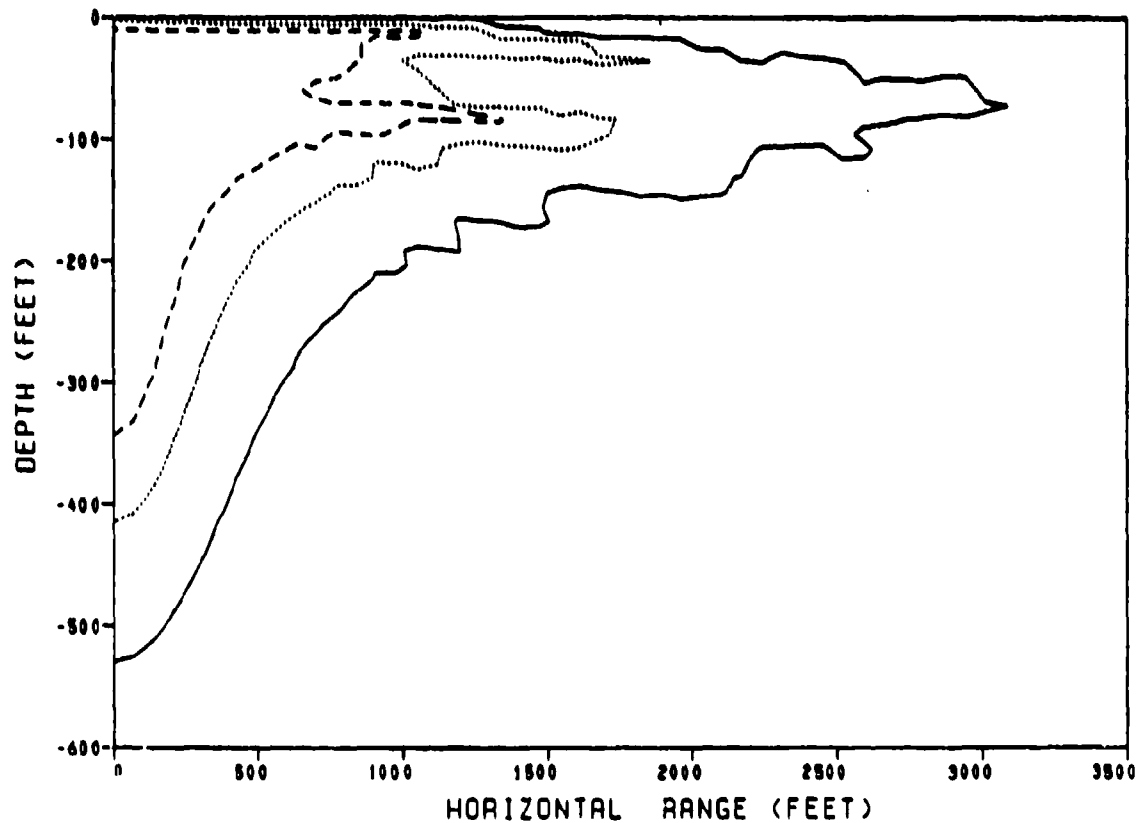


FIGURE 36. KILL PROBABILITY CONTOURS FOR 30-LB FISH; 10,000-LB PENTOLITE, 200-FT DOB

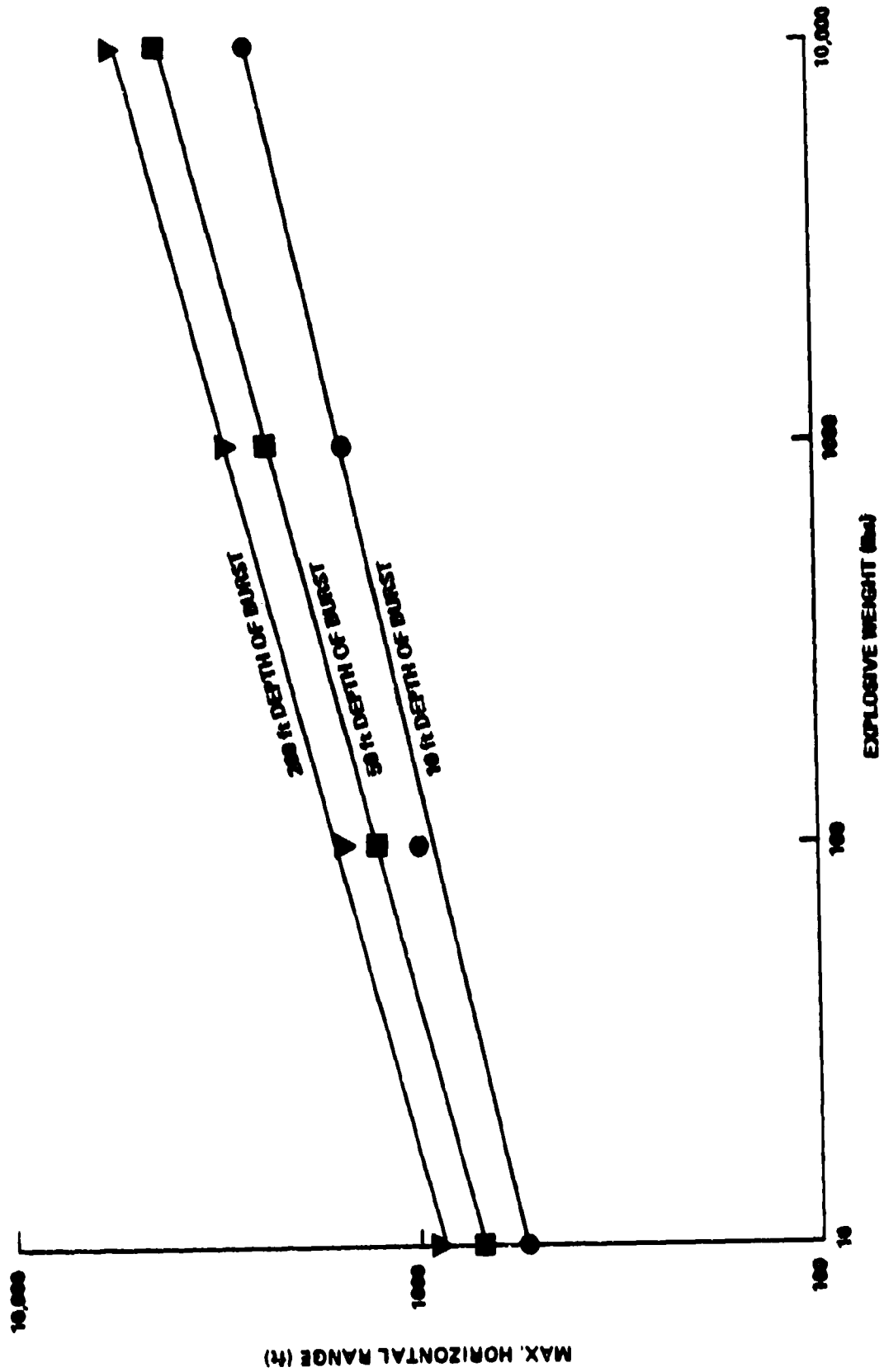


FIGURE 37. FISH-KILL RANGES FOR 100 LB FISH

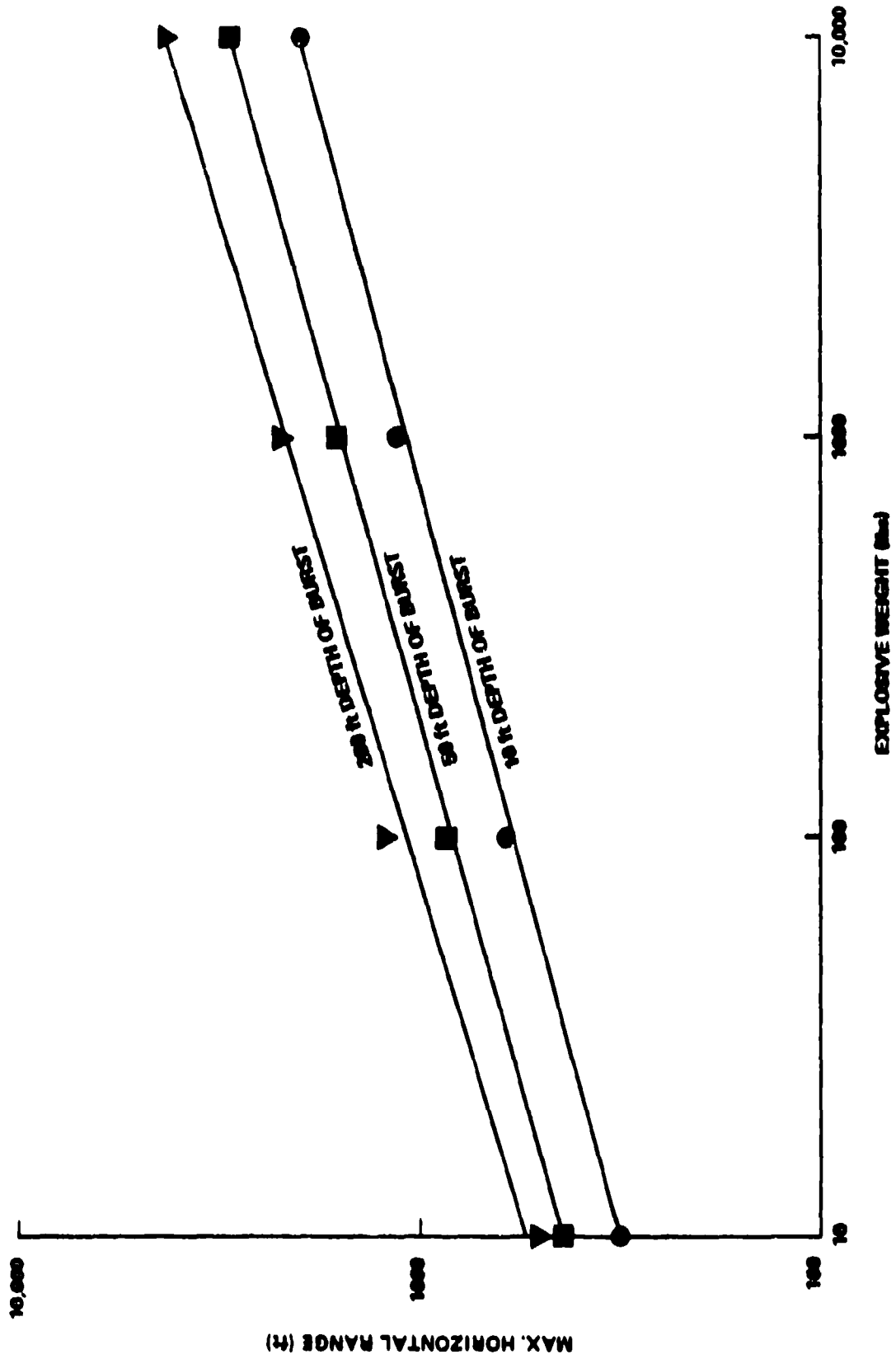


FIGURE 31. FISH-KILL RANGES FOR 1-LB FISH

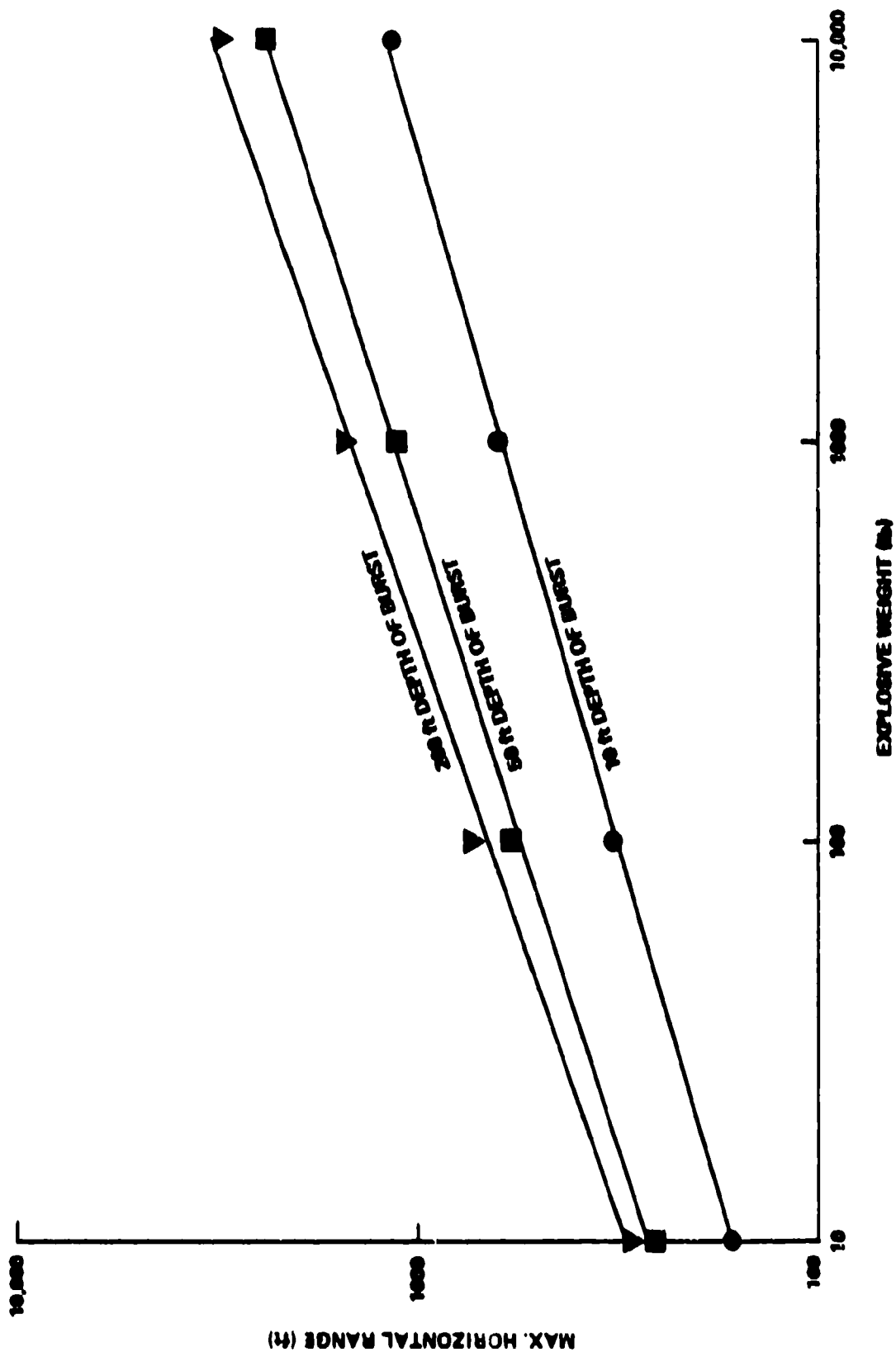


FIGURE 30. FISH-KILL RANGES FOR 30-LB FISH

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